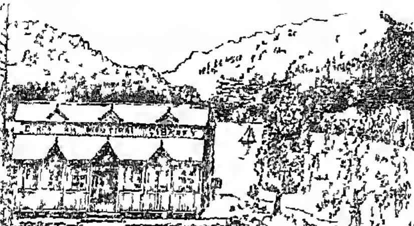

The New Farming

by

D. H. ROBINSON

This comprehensive book shows how farming has developed into one of the most scientific industries of all time, [illegible] the country's farmers, in their fight to grow food and save dollars, [illegible] and yet more from the [illegible]. It explains how the scientist is responding to the demand [illegible] by controlling the reproduction of animals, by breeding new plants, by discovering [illegible] killers of common [illegible], by vanquishing diseases, and by inventing new machines. Layman and countryman alike will be fascinated by these developments, while the specialist will find this survey a useful means of keeping up to date with matters touching his subject.

With [illegible] illustrations from photographs.

THE NEW FARMING

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by

D. H. ROBINSON

Ph.D., B Sc., N.D.A.

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TO

MY MOTHER AND FATHER

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PREFACE TO THE SECOND EDITION

Since this book was first published in 1938 the pace of the development and application of agricultural science has accelerated to a remarkable degree, and it becomes increasingly difficult to keep in touch with what is happening. I hope that this new edition, which has been rewritten and considerably enlarged, will provide the reader with a useful survey of the field, and will stimulate further inquiry into the fascinating study of the problems involved in crop and stock production.

My thanks are due to those of my colleagues who have given me their advice and criticism.

D.H.R.

Worcester 1951

PREFACE TO THE FIRST EDITION

This little book has been written in the hope of interesting the intelligent layman in the scientific side of agriculture, and of helping to dispel the idea that farming is an occupation suited only to the dull-witted members of a community. So much is written nowadays about the application of scientific methods to commercial undertakings that it is very desirable to restate the fact that agriculture makes as full a use of science as any industry in the country. Some of the ways in which science is being applied to farming problems are described in the following pages, and additional sources of information are indicated at the end of each chapter.

I take this opportunity of thanking numerous colleagues for their criticism and suggestions during the preparation of the manuscript, also those who have kindly placed photographic illustrations at my disposal.

D.H.R.

Harper Adams Agricultural College,
Newport, Shropshire,
May 1938

Chapter One

INTRODUCTION

Farming is not, and never will be, an exact science. Farming is an art, and to make a living a farmer must be both an artist and a business man. From a strictly materialistic point of view, business ability, not skill in cultivation nor scientific knowledge, is the most important single attribute to success in farming. Fortunately, most farmers are not narrowly materialistic, and whilst desiring to make a comfortable living for themselves and their families they also wish to do their duty by the land, to maintain it in good heart, and not tear out its goodness for immediate profit.

The intense competition brought about by modern conditions of life has made impossible the leisurely methods of farming which were practised during the nineteenth century. Diligence on the part of the farmer himself, together with plentiful applications of 'muck' and liberal supplies of oil-cake, are no longer sufficient to ensure success. Some knowledge of developments in modern science is essential if the farmer is to make the best use of the materials at his disposal. He must have a smattering of general scientific knowledge to enable him to buy his fertilizers and feeding stuffs to the best advantage, to manage his land, to protect his crops, and to feed and protect his animals.

His scientific attainments need not be profound, because the Government has put at his disposal certain specialists to whom he may turn when faced with an unusual difficulty. But he must have, as part of his general educational equipment, some understanding of the biological and chemical sciences if he is to pro-

duce crops or stock, which by his business ability he hopes to turn into profit.

The younger generation of farmers realizes and accepts as a natural thing this necessity for technical instruction. Some of them attend university departments of agriculture or agricultural colleges for courses of instruction varying from a few months to several years. Others attend county agricultural institutes, or put in an appearance at classes in various centres arranged by the county agricultural staffs. The older men, to whom these facilities were not available in their youth, are keen to make use of what science has to offer, and they turn up in large numbers whenever a good specialist is billed to discuss a subject which interests them.

Agriculture has, indeed, become a highly technical industry, and the townsman would be surprised at the scientific terminology which sometimes flavours the conversation of farmers gathered together in market and corn hall. Such phrases as 'crude protein', 'starch-equivalent', 'indigenous rye-grass', 'carotene content', 'CaO content', 'lamb dysentery', 'intradermal test', are commonplace, and indicate how closely science has become woven into agricultural existence—almost without the countryman being aware of the fact.

This unawareness on the part of farmers of the fact that they are becoming scientific in outlook is extremely encouraging and is a hopeful sign for the future. In the past there has been too great a tendency to exalt science at the expense of sound practical experience and observation; scientists are themselves considerably to blame for the disfavour with which many of their early efforts were received. Agricultural science is an applied science, and the technique of the laboratory cannot be applied to the farm. The research worker, unless he himself has good experience of farm conditions, is not the man to tell farmers about the supposed revolutionary nature of his discoveries. The results need to be passed through the sieve of practical farming knowledge before being generally recommended.

For this reason alone there is bound to be a lag between the discovery of a new scientific principle and its employment on

the farm. Prior to the 1939 war the lag might be considerable, amounting to ten or more years. Nowadays it is frequently very much shorter—indeed, there is a danger of untried ideas being pushed too energetically upon the farmer. A new idea formulated in the laboratory needs to be tested out on an experimental farm, such as that attached to an agricultural college, or maintained by a commercial firm. If successful, it can be recommended to the farming community. Farmers are naturally conservative, and they wait and see how the pioneers in the new method succeed or fail. If they succeed there is no lack of followers, provided there is no necessity for large capital expenditure. Those who complain at the farmer's slowness in adopting new scientific ideas should remember that his primary concern is to make a living, and that his amount of free capital is usually small. To risk capital in a more or less untried idea may be praised as pioneer work, but it is not the farmer's conception of sound business.

At no time in the history of agriculture has the agricultural mind been so receptive to scientific teaching, provided that it can be grafted on to the business of farming. In the following chapters some account is given of the numerous ways in which science is at this moment helping the farmer in his business. The arrangement of the material is obviously open to criticism because of the complexity of the problems that the agricultural scientist is called upon to solve. Soil fertility, for example, is not a matter entirely for the chemist. It demands the co-operation of at least the chemist, biologist, plant breeder, and engineer. Some overlapping is consequently unavoidable. The chief concern of this book is to indicate the application of science to everyday farming, not to give a résumé of current agricultural research. For a more detailed account of the technicalities involved the reader is referred to the publications mentioned at the end of each chapter.

COLLATERAL READING

The most important weekly papers entirely devoted to agricultural matters are *The Farmer and Stockbreeder*, *The Farmer's Weekly* and *Farming News and North British Agriculturalist*: the first two are published from London,

the last from Glasgow. *The Dairy Farmer* is published monthly. Most of the important principal daily papers in London and the provinces have an agricultural correspondent. *The Field* and *Country Life*, among weekly magazines, devote considerable space to farming topics. *Agriculture* is the name of the Journal of the Ministry of Agriculture: it is published monthly, and contains authoritative articles on all aspects of farming as well as official announcements. *The N.A.A.S. Quarterly Review* is primarily intended for officers of the National Agricultural Advisory Service, but can be bought by the general public. *The Scottish Journal of Agriculture* is published quarterly by the Scottish Department of Agriculture. *The Welsh Journal of Agriculture* is an annual volume. *Agricultural Progress* is the official Journal of the Agricultural Education Association and appears twice a year. *The Journal of the British Grassland Society* appears quarterly. The Royal Agricultural Society of England issues a Journal annually: with it is included 'The Farmer's Guide to Agricultural Research', which is a summary of the chief investigations under progress during the preceding twelve months.

Farming is a monthly publication which reviews the progress of agricultural science by means of articles contributed by specialists. Articles of direct agricultural interest appear occasionally in *Discovery*, a scientific monthly magazine. *New Biology*, a Penguin publication which appears at intervals, usually has at least one article of farming interest.

Technical papers on agricultural research are published in a great variety of scientific journals which cannot be listed here. Those who are interested in any special problem should consult the appropriate Department of the nearest University or Agricultural College, or the appropriate Provincial Officer at the nearest headquarters of the National Agricultural Advisory Service: addresses of these are given in Chapter Eleven.

The quantity of published agricultural research throughout the civilized world is so great that it is impossible for any one person to read all the papers connected with matters that affect even one particular aspect. To assist scientific workers numerous summaries or abstracts are regularly published. A list of abstract journals published in this country is also given in Chapter Eleven.

The two standard textbooks on agriculture are *Fream's Elements of Agriculture*, 13th edition edited by D. H. Robinson (John Murray, 1949) and *Agriculture*, 9th edition, by Sir J. A. S. Watson and the late J. A. More (Oliver and Boyd, 1949). A useful general work is H. Ian Moore's *Background to Farming*, (G. Allen and Unwin, 1947). Yearbooks which give a tremendous amount of detailed information about farming matters, including the names and addresses of Government and other Departments, are *Farming and Mechanized Agriculture* (Todd Reference Books Ltd., George G. Harrap and Co., Ltd.), and *The Farmer and Stockbreeder Yearbook*.

Two other recently published works on general agriculture are *Modern Farming*, edited by S. Graham Brade-Birks (Waverley Book Co., 1950), and *Progressive Farming*, edited by J. A. Hanley (Caxton Publishing Co., 1949.)

The Ministry of Agriculture publishes numerous leaflets and bulletins giving information and advice on all aspects of farming: some of these are

free for the asking, others cost from a few pence to several shillings. A list of the publications can be obtained from H.M. Stationery Office, Kingsway, London.

Readers' Guide to Books on Agriculture (The Library Association, February 1949) should be consulted for a selection of farming books published before November 1948.

Chapter Two

SOIL AND FERTILITY

Complicated nature of soil—soil classification—importance of size of soil particles—colloids—chemical analysis and its limitations—usual methods of diagnosing mineral deficiencies—tissue tests—methods of determining manurial requirements—Mitscherlich, Neubauer, 'Azotobacter' and 'Aspergillus' methods—importance of lime—hydrogen-ion concentration—soil indicator—estimation of lime requirements—sensitivity of crops to lime shortage—different forms of lime—waste lime—magnesian limestone—deficiencies of minor elements—manganese, magnesium, boron, iron and copper deficiencies—excess copper and zinc—humus—N.P.K.—compost—sewage sludge—hydroponics—synthetic nitrogenous fertilizers—phosphatic fertilizers—balanced fertilizers—storage of fertilizers—caking and setting—granular fertilizers—fertilizer placement—advantages and disadvantages of placing fertilizers close to seed—the combine drill

Plants, which are absolutely essential to animal life, obtain their nourishment partly from the soil and partly from the air. From the carbon dioxide of the air plants obtain, through the medium of their green colouring matter called chlorophyll, the carbon which is so essential to the formation of 'organic' substances such as starch, sugar, protein, and oil. From the soil plants obtain their water, their nitrogen, and mineral substances such as calcium, phosphorus, potassium, iron, etc. The atmosphere cannot be controlled by the farmer, though it has been demonstrated that increased growth of

plants can be obtained in special greenhouses where the proportion of carbon dioxide is artificially increased. But the soil can to some extent be controlled, or if not controlled can be coaxed into a condition favourable to the growth of plants—hence a great deal of scientific investigation has been directed towards the soil and its bearing upon fertility.

Modern research goes to show that the soil has a much more complicated structure than was thought to be the case at the beginning of the present century. For our present purpose we may consider that soil consists of mineral matter, organic matter, soil water, soil air, soil animals, and small soil plants. The fertility of a soil depends upon the interaction of all these components, hence it is obvious that the problem is a very complicated one.

Science is seeking to aid the farmer by tackling the problem in four main directions: classification, study of the physical characters, study of the chemical characters, and study of the biological factors in the soil. Of course, it is impossible to separate these factors in actual practice, but individual study is essential if accurate information is to be obtained in the end.

The classification of soils has undergone great developments since 1920, being stimulated by work carried out in Russia. Previously, much stress had been laid upon the relation of a soil to its geological formation, and very sweeping statements were made and deductions drawn from the evidence of geological surveys. Soil chemists of to-day do not deny that the underlying rock (geological formation) has a very great influence on soils, but they are now more inclined to study in detail the peculiarities of the soils themselves rather than base their conclusions upon the evidence of geologists. They demand soil surveys as distinct from geological surveys.

Soil surveys are not new. The early soil workers concentrated upon the first foot or so of the soil, and based their work largely upon its physical and chemical nature. They dealt with it in layers nine inches thick, starting from the surface. Numerous methods of analysis were in use, but the results obtained by workers in one area could not always be correlated with those

obtained in other surveys. Modern soil surveys are being conducted upon more or less standard lines throughout the country, so that the published data can be understood and interpreted by workers in different areas. There is, too, a tendency to pay more attention to what is called the 'soil profile', that is, the different layers of soil from the surface down to the parent rock. Samples of these different layers are analysed in the laboratory to obtain information about their physical and chemical composition, and the soils are then classified into series which can be indicated upon soil maps. These soil maps also include details of other matters of farming importance, so that a skilled man, looking at these maps, can gain a very good idea of the capabilities of any particular soil. Soil surveys are already proving very useful to those scientists whose business it is to advise farmers upon cropping and manuring, and there is no doubt that they will prove of extreme value as the mapped areas extend.

Surveys of this sort depend upon field examination and the analysis of soils, both physical and chemical. In physical analysis the size of the soil particles is of great importance, and so is the amount of organic matter. The organic matter, frequently and loosely called humus, is made up of rotting vegetable and animal matter, and since it is mainly that part of the soil destroyed by burning, it is determined by igniting the soil. The mineral part of the soil is separated out into various 'fractions' according to the size of its particles. The common fractions are:

	Having particles with a diameter of
Coarse sand	2 –·2 mm.
Fine sand	·2 –·02 mm.
Silt	·02 –·002 mm.
Clay	less than ·002 mm.

It has been found that the texture and behaviour of a soil depend very largely upon the proportions of 'clay' and silt relative to the amount of sand and modified by the organic matter present. Clay particles are very tiny, and expose a tremendous

area of surface: a cubic foot of clay may have a total surface of 100,000 square feet. The clay and the humus together form what is called the colloidal complex. It is not possible here to describe at all adequately what is meant by a colloid; it must suffice to say that a colloid consists of materials with remarkable powers of absorption and retention. A well-drained sandy soil is usually deficient in this colloidal matter, so that it will not retain the soil water, and soluble fertilizing material washes out very readily. In some clay soils, on the other hand, there may be an excess of this material, with the result that too much water is retained and the amount of air present in the soil becomes insufficient for healthy root growth.

The discovery of the colloidal behaviour of soils is greatly influencing modern research, but the investigations are extremely technical in character. It has been found that the amount of calcium in a soil exercises a great influence upon the soil colloids. It causes the tiny colloid particles to unite or coagulate into larger particles—the process is called flocculation. In a clay soil this flocculation is of considerable benefit to the texture of the soil, and it partly explains why the application of lime (either as calcium oxide or calcium carbonate) is so useful.

The mechanical analysis of a soil, that is, an investigation into the size of the soil particles, can by itself give much information to the soil chemist. For example, a soil containing 30 per cent each of silt and clay would be a very tenacious one, suitable for growing field beans; a soil with 30 per cent silt and 20 per cent clay would be likely to grow good wheat. A good barley soil would probably have 25 per cent of fine sand and about 40 per cent of silt, whilst a soil with 50 per cent coarse sand and about 15 per cent each of fine sand and silt would most likely prove profitable under market garden cropping and sugar beet.

But mechanical analysis alone does not tell us everything; some indication of the chemical nature of the soil is also desirable. Experience shows that in the majority of soils only four major elements are likely to be deficient from the point of view of plant nutrition—namely, calcium, nitrogen, phosphorus, and potassium.

The total amount of these elements in a soil is very large, but only a proportion is at any given time capable of being absorbed by the roots of plants. This fact was not properly realized by the early analysts, whose conclusions and recommendations were often so much at variance with the experience of farmers that for a time the chemical analysis of soils was regarded with distrust. But towards the end of last century it was found that a very good idea as to the 'availability' of the mineral elements, and especially of phosphorus and potassium, could be obtained by shaking up a soil with a 1 per cent solution of citric acid, and analysing the liquid under standard conditions.

During the last fifty years enormous numbers of soil analyses have been made: many thousands were made during the food production campaign which began in 1939 and they formed useful guides to cropping and manurial programmes. As a rule, they were concerned only with the calcium, phosphorus and potash status of the soil, for it is generally assumed that soils in Britain are always more or less deficient in nitrogen. Because of the great development in soil sampling and soil analysis farmers are prone to regard these chemical tests as an unfailing guide to correct manuring and an infallible answer to soil problems. But this is not the case. A chemical analysis will provide most useful information about the acidity or alkalinity of a soil, and it will also give an indication of deficiencies of phosphate and potash. But if the data so obtained are to be used to the best advantage to the farmer they must be interpreted by an experienced man, who must also know something about the nature of the soil and subsoil as it exists on the farm, its drainage, the system of farming practised and so on. It is most unwise to attempt to advise farmers merely from the results of an analysis of an unknown soil from an unknown farmer, a procedure which is frowned upon by all responsible scientists and technical advisers.

Chemical soil analyses need plenty of laboratory space and equipment, together with the necessary analysts, and they are expensive and comparatively slow, despite the growing adoption of colorimetric methods of estimation in place of the original methods. During the last ten years much attention has been paid

to visual methods of diagnosing mineral deficiencies. If plants are grown in water culture or sand culture (i.e. not in soil) and are fed by means of solutions of pure chemicals, it is possible to omit at will any particular element, such as phosphorus, boron or potash, etc. A plant growing in a medium which lacks potash, for example, will exhibit certain specific symptoms, including 'scorched' leaf margins, curling of the leaf, stunted growth and so on. The symptoms vary in different plants, but with experience it is possible to recognize the symptoms for most of the major deficiencies and some of the minor deficiencies, in all the common farm crops. Books and bulletins are now available in which the chief deficiencies are explained and illustrated by means of photographs in natural colour. A trained observer can diagnose soil deficiencies from an inspection of the growing crop, and can in many cases advise an immediate treatment which may save the crop. The visual diagnosis of major deficiencies can, of course, be checked by a soil analysis.

Another way of diagnosing deficiencies is a complete chemical analysis of the foliage. This line of work has been followed mainly with fruit trees and, subject to certain safeguards, has given useful guidance upon nutrition. But, as with soil analysis, much time, labour and equipment are needed. A more rapid method which has been developed during the last decade is the 'tissue test'. This originated in America and has been worked upon over here chiefly at the Long Ashton Research Station. The test is carried out on the leaf stalks, or petioles, of the plant under trial. Small sections are immersed in Morgan's reagent (a mixture of glacial acetic acid and sodium acetate) for fifteen minutes, and the extract is then tested with various chemicals. Changes in the colour and turbidity of the liquid indicate the relative sufficiency or deficiency of the various elements concerned in the nutrition of the plant. The tissue test is rapid and requires only very simple apparatus; it can be carried out in the field if necessary, and although only in its infancy it gives great promise.

Other field methods of overcoming deficiencies include the injection of chemicals into the stems and branches of woody plants, and the spraying of foliage of both woody and herbaceous plants.

In the laboratory, methods of soil and plant examination by means of the spectrograph are developing, but the apparatus required is so expensive that so far only a few research centres are equipped for the work.

In Germany a method of obtaining information about the manurial requirements of soil was devised some years ago by Mitscherlich. It is based upon the yield of dry matter produced by oat plants growing in pots of the soil under test, under different manurial treatments. It achieved considerable success despite the disadvantage that it takes a full growing season and is expensive because of the number of pots to be looked after. Another German method was invented by Neubauer. It is based upon the way in which the seedlings of rye can extract phosphate and potash from different soils in pots kept under standard conditions. Neither of these methods has achieved popularity here, though the Neubauer method has been used to some extent in advisory work on sugar beet manuring.

Both the Mitscherlich and Neubauer methods require much careful supervision and neither is suitable for the ordinary laboratory. A simpler method makes use of a soil micro-organism called *Azotobacter*. The soil to be tested is mixed up into a paste with starch and china clay and divided into various portions; phosphate is added to some portions, potash to others. The pastes are put into an incubator kept at a temperature of 30 degrees for twenty-four to forty-eight hours. The organism forms small specks or colonies. If the soil contains sufficient phosphate and potash there is no difference between the number and size of the colonies in the differently treated samples. If, however, the soil is deficient in potash, the dish receiving extra potash will show a more vigorous growth; a deficiency in phosphate is indicated in a similar manner. A scale has been devised whereby it is possible, on broad lines, to correlate the growth of the colonies with the actual requirements of a soil.

Yet another method depends upon the growth of a mould, or fungus, called *Aspergillus*, in a culture solution to which soil has been added. By varying the culture solution, and weighing the felt-like mass of the fungus which forms at the end of several

days' incubation, it is possible to get an idea as to the requirements of the soil in potash and phosphoric acid. All these methods are somewhat academic and in this country are overshadowed in importance and value by the methods of soil analysis and visual diagnosis already mentioned.

One of the most serious problems in modern farming is that of soil acidity. An acid or sour soil is one that is deficient in lime, and profitable crops cannot be grown in it. The very serious deficiency of lime in farm soils in this country was recognized many years ago, and shortly before the 1939 war the application of lime was subsidized by the Government. But the outbreak of war emphasized the fact that one of the major bars to increased food production was this acidity or sourness of the soil.

The scientist is here called upon to do two things: first, to recognize the degree of acidity in any particular soil, and second, to recommend a dressing of lime which will be sufficient to overcome the acidity without being unnecessarily extravagant. To apply too little lime is useless; to apply too much is wasteful, because lime soon disappears from the soil and its effect is lost.

Years ago farmers were recommended to shake up some of their soil with a small quantity of hydrochloric acid (spirits of salt) in a tumbler, and listen for a fizzing sound or watch out for bubbles. If these were not forthcoming the soil was considered to be in need of lime. This test is of very limited value. Nowadays, the intensity of acidity in a soil is measured by the hydrogen-ion concentration, and is expressed by the pH number. On the hydrogen-ion concentration scale a neutral soil would be represented by the number pH7, a strongly acid soil by pH4·5, a slightly acid soil by pH6·0–6·5. A soil with a pH7·1 would be alkaline. In other words, the lower the pH figure, the greater the acidity. British soils range from pH3–pH8. Under farming conditions it is commonly agreed that any soil having a pH figure above 6·5 can be regarded as non-acid. It does not pay to raise the hydrogen-ion concentration above this figure and attain absolute neutrality, or even alkalinity.

For accurate work the hydrogen-ion concentration is determined by an electrical method, but it is possible to obtain an

approximate idea by the use of special coloured solutions. One of the most popular 'soil indicators' is a solution of bromo-thymol-blue and methyl red. A few drops of this mixed up with a small quantity of acid soil will give a reddish or orange colour; if the soil is non-acid, the solution remains blue or bluish-green. Use of the soil indicator gives a general idea as to the reaction of the soil, and in experienced hands can be very helpful. Electrically determined, however, the hydrogen-ion concentration provides accurate and valuable information.

Recent investigations have shown that the colloidal matter previously referred to is the seat of the reaction changes in a soil —that is, it causes acidity or alkalinity. The particles have loosely attached to them both acidic and basic material; a predominance of the former causes an acid soil, of the latter a non-acid soil. The only basic material of any importance in this connection in English soils is calcium, which can be supplied to soil in the form of lime. The pH figure does not tell an analyst how much lime must be added to a soil to counteract any given acidity, so special methods have to be used.

One widely used method of determining 'lime requirement' is the Hutchinson and McLennan method. Here the soil, when treated with calcium bicarbonate, absorbs some of the calcium; the amount absorbed gives a measure of the amount of lime (calcium oxide or calcium carbonate) needed to bring about non-acid conditions. There are also titration and other methods; by using these, soil chemists are able to gauge fairly accurately the most economical rate at which to apply lime on any particular soil. The estimation of lime requirement is a routine process, but advice based upon it must be given in the light of field experience. In all work on soils designed to assist the farmer, practical acquaintance with the soils as they are on farms is just as important as laboratory analyses.

Morley Davies and other workers have shown that certain crops can survive a considerably greater soil acidity than other crops, and they have tentatively classified plants into three groups: sensitive crops, such as red clover, sugar beet and barley, which die out or do badly at a pH of 5·5 to 5·2; moderately

sensitive crops, including wheat, turnips and cabbage, which fail at pH values of 5·1 to 4·8; and non-sensitive crops, wild white clover, kale, oats, potatoes, rye which fail when the soil pH is from 4·5 to 4·1. Over considerable areas of the country at the outbreak of the 1939 war the soil was too acid even for potatoes, and the great potato-growing drive on the Montgomery hills suffered greatly from acute lime shortage in its first season.

The value of lime on farmland is, of course, by no means a new discovery, because many of the virtues of the substance were recognized a century or two ago, and our forefathers were in the habit of spreading over their land large amounts of calcium in the form of lime, chalk, and certain types of sea sand. But between 1940 and 1945 a great deal was learned about the value of the different forms available. Lime is calcium oxide (CaO) and does not occur naturally: it is formed when either limestone rock, or chalk (calcium carbonate), is burnt in kilns. When limestone is burnt the end product (after the carbon dioxide has been driven off) is burnt lime containing about 95 per cent CaO. It is obtainable as lump lime, ground burnt lime or quick lime. It is very caustic and unpleasant to handle, is very liable to absorb moisture and therefore bursts its containers during storage. Sometimes the burnt lime is slaked and ground up, and is sold as hydrated lime. These forms of lime were the most popular prior to the war. But during the war there were shortages of manpower and fuel, while the black-out still further complicated the burning of lime. Consequently, more and more attention was directed to ground limestone, that is, the limestone rock milled to a fine state of division. This contains only about 50 per cent CaO compared with the 95 per cent present in burnt lime. But ground limestone has the advantages of being non-caustic, less unpleasant to handle, and less liable to burst its containers, in addition to which it is less expensive to produce than burnt lime. To get the same results as one ton of ground burnt lime, an application of 35 cwt. limestone is necessary; but the disadvantage resulting from increased bulk compared with ground lime is offset by the advantages possessed by ground limestone already discussed.

Until a few years ago it was thought that limestone must be

ground very fine if it is to be of maximum use, but this has now been disproved. It is now suggested that a limestone, all the particles of which will pass a 20 mesh to the inch sieve, is sufficiently finely divided for ordinary farm purposes. The dust particles become available immediately, and the coarse material acts as a reserve for following years. This, of course, is a most useful discovery, since it naturally costs more to grind the limestone very fine than to a relatively coarse state.

The use of waste limes, particularly those from sugar beet factories, has also received a lot of attention. They usually contain a lot of water, which is a disadvantage as it adds to transport costs. They may contain small amounts of fertilizing elements of appreciable value when ten tons or more of the waste lime are applied per acre, and significant amounts of 'trace elements', which are described later. Some factory waste limes may contain toxic compounds rendering them dangerous to crops. Obviously, therefore, the advice of the agricultural chemist should be obtained before waste limes of unknown nature are used on the farm.

There has been an interesting change of opinion about magnesian, or Dolomitic, limestone during the last forty or fifty years. For a long time it was looked upon as toxic to both soil and plants, and limestones having more than 25 per cent magnesium oxide (MgO) were thought to be useless for farm purposes. But since about 1920 evidence regarding magnesium deficiency in crops has accumulated, and it is now recognized that magnesian limestone in moderate amounts is not only a useful corrector of soil acidity, but also adds to the soil some much-needed magnesium.

It has already been explained that crop yields are influenced very markedly by the availability of calcium, nitrogen, phosphorus and potash in the soil, and that modern methods of manuring, apart from the provision of humus, are based upon these facts. But it has been shown that in some circumstances crops may suffer because of lack of available 'minor' or 'trace' elements (or micro-nutrients, as they are now being called) in the soil. These minor elements are needed by plants only in

very small amounts, yet if they are absent or unavailable satisfactory growth is impossible. The most important minor elements are manganese, magnesium, boron and iron, though deficiencies of copper and zinc may also occur.

Manganese deficiency may seriously affect the growth of oats, which suffer from the complaint called 'grey speck'. The leaves are spotted or striped with greyish patches, and later they bend and break in the middle in a very characteristic fashion. In peas, manganese deficiency is responsible for a disease called 'marsh spot', which for many years was quite inexplicable. Potatoes and sugar beet may also be affected. Manganese deficiency usually occurs only on soils which are alkaline and very well provided with organic matter. Applying excessive quantities of lime to black sandy soils may induce manganese deficiency diseases. It is possible to control the disease by applying manganese salts to the soil, and by spraying affected crops with solutions of manganese sulphate or chloride.

Magnesium deficiency may cause considerable loss of crop in sugar beet, potatoes, brassica crops and fruit trees. Fortunately, it can be counteracted fairly easily by using a magnesian limestone (i.e. a limestone containing magnesium) instead of the usual forms of lime. The disease in sugar beet known as 'heart rot' is caused by a deficiency of boron. In this complaint the crown of the plant turns black and rots away. For a long time it was thought that it was caused by a fungus or bacterium, but after lengthy investigations it became apparent that lack of boron is the cause. The disease called 'Raan' or brown heart in turnips and swedes is also due to boron deficiency. The application of borax at the rate of 14–20 lb. per acre, or the use of boron-containing fertilizers, controls the disease. For reasons not properly understood, farmyard manure also reduces the incidence of the disease. In fruit trees shortage of iron brings about a chlorosis, or pale, unhealthy foliage, a condition intensified by excess liming. The injection of iron compounds into the wood of the tree, and undercropping of the orchard with clover and grass, help to ameliorate growth of the fruit trees.

Animals as well as plants may suffer from deficiencies of

the minor mineral elements. Copper and cobalt, for example, in minute traces appear to be essential to healthy growth of livestock, and recent work on the control of some of the more important deficiency diseases in animals are described in Chapter Eight.

It is now known that an excess of certain minor elements in the soil can cause unhealthy plant growth. Excess copper or excess zinc have on occasion led to considerable losses. Heavy applications of lime have been instrumental in overcoming these complaints.

The humus part of the soil has received a great deal of attention during the last ten years or so. It is not at all easy to give an accurate scientific definition of 'humus', but it is sufficient for our present purpose if the term is taken to mean the decomposing vegetable and animal residue, or the 'organic' part, of the soil. The terms 'humus' and 'organic matter' are not synonymous: a dead root lying in the soil is organic matter, but it does not become humus until it has been physically and chemically changed by soil fungi and bacteria. When straw is trampled in a bullock yard it is turned into foldyard manure or dung, which in a well-rotted or 'short' condition can be regarded in a very general sense as humus. When straw or other vegetable material is rotted down in a compost heap, a considerable amount of humus is formed. When a stubble, or a clover ley, is ploughed into the soil, decomposition of the roots and stems takes place and the soil is replenished with organic matter. In the well-farmed districts of this country, as in Europe as a whole, farmers have for several centuries taken great pains to maintain the humus in their soils mainly by applications of dung or by ploughing in clover leys.

Until quite recently, of course, dung was the only manure available in this country but, with the opening up of the New World, nitrogenous fertilizers like guano and nitrate of soda became available; then, from 1843 onwards, when Lawes invented his superphosphate, came all sorts of 'chemical' fertilizers supplying in various forms phosphorus, potash and nitrogen. These three elements, singly or in combination, were found to give

remarkable erop increases on many soils and, as a result of numerous plot and field experiments, it beeame established that on most of our farms the limiting faetor in erop produetion is a shortage of N.P.K. (nitrogen, phosphorus, potash) either as a whole or singly. But it was also discovered that if crops are grown repeatedly with these chemieal fertilizers, without any attempt to renew the humus of the soil, erop yields diminished and eonsiderable damage eould be done to the soil itself. Light sandy soils became powdery and 'blow-away': stiff clays beeame stiffer and more unkind, diffieult to bring into a tilth, and so on. For humus binds together a soil in which the partieles are large, as in sandy or gravelly soils: yet helps to open up a soil whose particles are very small—clays and alluvial soils. It retains moisture and it has a most important benefieial influenee upon the fungi, bacteria, earthworms and other living organisms. These properties have been reeognized and appreciated both by the seientist and the thoughtful farmer in many countries. Where the humus status has been neglected, as for example in parts of North America where 'dust-bowl' conditions have developed as a consequence of repeated cropping without replacement of humus, most serious results have followed, leading to total loss of topsoil and complete extinction of farming.

During the last two decades a great deal of publicity has been given to the views of those who claim not only that humus is quite essential to healthy plant growth but also that chemieal fertilizers are deleterious both to plant and to the soil. It has already been pointed out here that both seientists and farmers in this eountry at any rate are agreed upon the neeessity for maintaining humus in the soil: very few farmers think that fertilizers alone (without dung, compost, green manure or organic fertilizers) can maintain the fertility of soil. Farmers and scientists are consequently in agreement with the 'humus school' on the need for humus. But they are far from convinced that fertilizers have the evil effeets upon plants and soil so vigorously elaimed by the humus school. Nor can they agree with the statement that crops grown with ehemical fertilizers are injurious to the health of human beings consuming them.

The controversy is further complicated by the arguments adduced in favour of manuring by means of compost. The process of composting is essentially a controlled rotting down of animal and vegetable wastes, the final product being a fine, friable mould which encourages root growth and general development in plants. Compost can be made in various ways. The natural method, where plant remains are merely thrown into a heap, is a slow one. The process can be speeded up if the heap is turned at intervals, because the turning allows air to penetrate to all the layers, whereas in a large heap the natural settling of the material drives out the air: and most of the fungi, bacteria and other agents of decomposition need air (i.e. oxygen) in order to live and work. The addition of lime and soluble nitrogenous fertilizers also hastens the formation of compost, though the use of fertilizers for this purpose is frowned upon by the no-fertilizer school. Further information about composts is given in Chapter Nine. Composts are mentioned here because of their undoubted success in maintaining soil fertility, though the special advantages claimed for them (such as complete elimination of plant pests and diseases) by certain enthusiasts are still a matter of controversy.

It is frequently suggested that sewage sludge should be more widely used as a source of humus in manuring farm soils. Unfortunately, sewage sludge contains no coarse fibrous material and therefore has very little beneficial effect on soil texture. When sewage undergoes treatment at a sewage works the suspended solid material is caused to separate out by sedimentation in tanks. The original sewage contains about one part by weight of solid matter in 1,000, the sediment from 4 to 10 per cent. The sediment may forthwith be dried in lagoons or drying beds, or it may first be 'digested', or subjected to treatment by aerobic bacteria. Almost all the potash and from one-half to two-thirds of the nitrogen and phosphoric acid in the original sewage are carried away in the sewage effluent. Partially dried sludges contain about equal proportions of organic matter and ash, or silt. The proportion of organic matter may be appreciably higher than it is in farmyard manure, but it is so finely divided that it

cannot influence the physical condition of the soil in the way that strawy dung can do. It is, of course, possible to make compost of sewage sludge and straw; these sewage composts have given results in field trials slightly inferior to dung. The bar to full utilization of sewage sludge or sewage composts is not so much the difficulty of making the material, but of cost of transport to the farm after manufacture.

Since 1929 there have been considerable developments in what is called *hydroponics*, or soil-less culture of plants. The scientist has for very many years used water cultures in his experiments with plants: he has grown his seedlings in bottles with their roots dangling in a weak solution of various chemicals. If certain precautions are observed, such as keeping sunlight from the roots and aerating the solution at intervals, such seedlings will grow vigorously and will come to maturity—provided always that the solution contains all the necessary mineral elements. A variation on the method is to grow the seedlings in a sterile medium like sand or ashes, and water them at intervals with the solution. In America in particular the solution culture system has been adapted to the raising of commercial crops. The plants grow in litter placed over large tanks, and are crowded much more closely together than is possible or desirable out in the field or garden. In the warm sunny climate of California and other places heavy crops have been produced, from four to ten times heavier than those on a similar area of land. But in England successes with solution culture have so far not been achieved, and sand or aggregate cultures have been found more successful than water culture. Obviously the cost of supplying tanks, glass-houses and other equipment for soil-less culture must be very great, and the commercial development of the system is likely to be slow.

Science has been of the utmost value to the farmer in the case of nitrogenous fertilizers. It will be recalled that not so very long ago, about the end of last century, it was thought that the world would soon be faced with a shortage of nitrogen, and that food production would in consequence suffer a severe decline. The first substance rich in nitrogen to be used as manure was nitrate

of soda, which was first imported from Chile in 1831. This material contains about 15½ per cent of nitrogen, and it soon became very popular. Guano, the dried excrement of sea birds, deposited in rainless areas along the coasts of Peru, contains about 8 per cent nitrogen, plus a certain amount of phosphoric acid and potash; it was first imported into England in 1840. For a long time farmers had no other choice of nitrogenous fertilizer; then, with the development of the gas industry, considerable amounts of sulphate of ammonia became available. This substance is formed by neutralizing with sulphuric acid the ammonia driven off during the distillation of coal to form coal gas. But even the large supplies of this fertilizer failed to satisfy the world demands for nitrogen.

The idea of extracting nitrogen from the air for commercial and agricultural purposes has long fascinated the chemist. The atmosphere is composed of approximately four parts of nitrogen to one part of oxygen, yet, with only one or two exceptions, plants are unable to make use of this atmospheric nitrogen for growth. A successful method of nitrogen extraction from the air would obviously do away with the bogy of a nitrogen shortage, and make possible a much more intensive system of crop fertilization. It was not until 1904 that this dream was first realized. In that year nitrogen from the air was caused to combine with calcium carbide in an electric furnace to form calcium cyanamide, a greyish powder containing about 20 per cent nitrogen. Calcium cyanamide, also called nitrolim, is used both as a nitrogenous fertilizer and as a destroyer of certain weeds.

From 1914 onwards there were tremendous developments of a process invented by Haber in Germany. In this process, known as the Haber-Bosch process, hydrogen derived from water gas is caused to combine with atmospheric nitrogen to form ammonia. A pressure of 200 atmospheres and a temperature of 500 degrees C. are required, as well as the presence of certain chemicals which act as catalysts. The ammonia gas can be turned into sulphate of ammonia by treatment with sulphuric acid; or into ammonium phosphate by treatment with phosphoric acid, or into nitric acid by oxidation. During the last few years the pro-

duction of this 'synthetic' sulphate of ammonia has increased enormously. For example, during the period 1948/49 the United Kingdom consumed for agricultural purposes more than 185,000 metric tons of nitrogen, about two-thirds of which was in the form of sulphate of ammonia. World consumption of pure nitrogen for all purpose during this period was over 4,100,000 tons, of which 85 per cent was used as fertiliser, an increase of about one million tons over the amount used in 1938/39.

During the Haber process of extracting nitrogen from the air, considerable quantities of calcium carbonate (chalk or lime) are thrown out as a waste product. During the early years of the development of the process this lime was sold cheaply in order to dispose of it, but now it is used at the factory in the manufacture of Nitro-chalk. This is a proprietary mixture of ammonium nitrate and calcium carbonate, and it is greatly liked by farmers for application to land where sulphate of ammonia is not altogether desirable. Sulphate of ammonia in large quanquantities tends to make a soil acid, whereas nitro-chalk contains much free lime.

The provision of plentiful supplies of phosphatic fertilizers has had a profound influence upon modern agriculture and agricultural research. Previous to the work of Liebig, the great German chemist, in the early part of last century, bones were almost the only source of phosphoric acid available to farmers. They were finely ground, but the supply was limited and the manure was slow acting. By treating bones with sulphuric acid Liebig made 'superphosphate', a much more rapidly acting fertilizer. Lawes, in 1842, took out a patent for the manufacture of superphosphate, using mineral, or rock, phosphate instead of bones. This phosphatic manure proved extremely useful and did much to improve the fertility of light lands specially suited to growing turnips. Lawes made a big fortune, and founded the first agricultural experiment station in the world at Rothamsted, near Harpenden in Hertfordshire. More recently, since about 1920, the phosphatic rocks themselves have been used, without the treatment with sulphuric acid. The idea of using the acid is to

change the insoluble phosphate into a soluble form available to plants. It has been discovered that by grinding the rock to a very fine powder the phosphate will dissolve to a certain extent in the soil water, and ground rock phosphate is now a recognized source of phosphoric acid. It is best used on grassland in the wetter districts of these islands, and on acid arable soils.

Basic slag, of course, owes much of its value to the fineness of the powder to which it is ground. Basic slag is a waste product of the steel furnaces during the manufacture of steel from phosphatic rocks containing iron. For many years this slag was a nuisance to the iron companies, and accumulated in great heaps. About 1885 it was discovered that finely ground slag may be as good a source of phosphoric acid to crops as superphosphate in certain soils; since then it has proved a profitable sideline to the steel companies and a most valuable manure to farmers. It should be ground so small that 80–90 per cent will pass through a sieve having 10,000 meshes to the square inch. Investigations carried out early in the present century showed that basic slag has a very stimulating effect upon wild white clover (see p. 80), and to this combination much of the fertility of the grasslands of the country is due. Basic slag is rather more lasting in its effects than superphosphate, and it is also a home-produced fertilizer; these two facts no doubt influenced the Government when they decided, under the Land Fertility Scheme of 1937, to subsidize the application of basic slag to agricultural land. Owing to recent changes in methods of making steel, high-grade basic slags are not so plentiful as formerly. Some of the low-grade slags are of very limited value as phosphatic fertilizers.

During the food production campaign from 1940 onwards there was a great scarcity of phosphatic fertilizers; the shortage was alleviated to some extent by imports from the U.S.A. of triple-superphosphate. This is made by treating phosphatic rock with phosphoric acid instead of with sulphuric acid, with the result that a much more soluble phosphate is formed, having about 48 per cent phosphoric acid instead of the 16 to 18 per cent in ordinary superphosphate. Farmers in this country were at first rather sceptical of this concentrated form, but the great

convenience in handling, plus the good results obtained with it, soon created a big demand. Triple superphosphate will shortly be manufactured in this country and for the time being is unobtainable.

Another concentrated phosphatic fertilizer, ammonium phosphate, has become available in recent years. It contains 42 per cent phosphoric acid and 11 per cent nitrogen, and is extremely soluble. It has become well liked as a fertilizer for use in preparing the ground for a direct seeding of a ley (see p. 85), and is probably the best material for top dressing winter wheat to overcome a deficiency of phosphates.

Although many farmers make up their own fertilizer dressing by mixing together the various ingredients like sulphate of ammonia and superphosphate on the barn floor, yet there is an increasing tendency to purchase ready-mixed compound fertilizers. In their turn, manufacturers of these compounds are turning more and more to granular fertilizers.

The introduction of ammonium phosphate has made possible the manufacture of compound fertilizers containing almost twice as many units of the standard nutrients as the older types. These concentrated complete fertilizers require less space and are more easily transported: they are granular in texture and consequently easily handled and distributed on the farm.

Compound fertilizers are often described as 'balanced' for certain crops: 'balance' as used here is not a strict scientific term, but reflects observations and results of trials, which show that different crops require different proportions of nitrogen, phosphate and potash. Generally speaking, cereals need a relatively high nitrogen ratio, potatoes need much potash, turnips much phosphate, and so on. A development in fertilizer balance which has attracted much interest during the last few years is the discovery that two fertilizers used in combination may result in a crop yield which is greater than the sum of their individual effects when used singly. On the other hand, there are cases where one fertilizer may reduce the beneficial action of another, as for example potash and salt on sugar beet.

Before 1939 the manufacturers of chemical fertilizers were able

to cope adequately with seasonal demands by running their works at full pressure just before the autumn and spring rushes. Farmers were able to obtain their supplies just before the sowing seasons, and the fertilizers remained in the bags only a short time before being sown. But after 1940, as the increase in the arable acreage developed, the demand for fertilizers became tremendous. Manufacturers were no longer able to work on a seasonal basis: they were compelled to go on manufacturing throughout the whole of the year. But they were able to do this only if the fertilizers were removed from their works shortly after manufacture, otherwise their storage space became glutted and work had to cease. Merchants had to take more and more fertilizers into store, until their storage space, too, was glutted. Consequently, merchants had to encourage their customers, by means of price rebates, to take the fertilizers on to their farms and store them until wanted. Thus it happened that sulphate of ammonia, for example, needed for top dressing cereals in late spring, might be delivered at the farm many months in advance.

This sort of arrangement was not altogether satisfactory to the farmer. He realized that if he was to rely upon having the fertilizer when he wanted it he would have to assist the manufacturer and distributor by storing it. But on many farms proper storage space is scanty and is often far from being really dry. Even in the best of conditions the compound fertilizers, especially those containing much potash, are very liable to cake or 'go hard'. This entails a great waste of time and labour in breaking up the material to enable it to go through a fertilizer drill. Manufacturers, of course, have realized this for a long time, and to some extent the trouble has been overcome by the development of granular compound fertilizers. A compound fertilizer is made by mixing together certain raw materials like sulphate of ammonia, superphosphate and muriate of potash in specified proportions to give a fertilizer having a guaranteed analysis of nitrogen, phosphoric acid and potash. As soon as the ingredients are mixed certain physical changes occur, with the development of masses of crystals which cause the mixture to 'set' hard. The crystals

have to be ground or milled, after which there is no danger of further setting; the composition of milled material in terms of N.P.K. is not affected by the processes of setting or milling. But although the process of crystallization called setting does not recur, a somewhat similar process called 'caking' can quite easily take place through the absorption of moisture followed by partial drying. Certain fertilizer materials, particularly those containing potash, readily take up moisture from the air even if stored under what may seem to be good conditions, and surface crystallization can take place, causing the bulk to become caked together. To a large degree this caking can be prevented by mixing in with the fertilizer ingredients about 10 per cent by weight of a 'conditioner' or 'dryer': steamed bone flour, finely ground peat, ground cocoa shell and dolomite are commonly used conditioners. It was in this way that most compound fertilizers were manufactured until recently.

Granulation of fertilizers tackles the problem of setting and caking in a different fashion. The mixture of fertilizers is sprayed with water as it passes through a long cylinder, and forms a paste. The rotation of the cylinder causes small granules to form and these are dried rapidly in a rotary drier: the granules pass through a cooler and are at once bagged off. The initial recrystallization which causes setting takes place within each granule, and there is consequently no setting between granule and granule. Further, since the granules themselves are very hard and because they have an exposed surface much less extensive than that of the ordinary powdery materials, there is not the same tendency to absorb moisture and so to cake in the bags. But, of course, if stored for a long time in a damp barn, even granular fertilizers will deteriorate, though the deterioration is usually towards a pasty condition rather than towards caking.

It has already been said that granular fertilizers have a much smaller exposed surface than an equivalent weight of a powdered fertilizer. This reduced surface means that the granules dissolve more slowly than the powders, and it is claimed that this is a considerable advantage. Instead of dissolving at once in the soil water and so providing an excess of plant food later to be fol-

lowed by a shortage, the granules provide a steady flow of nutrients over a long period.

In the case of phosphatic materials, this slow solution reduces the amount which becomes 'fixed' in the soil and so lost to the plant. In average conditions about 75 per cent of the phosphates applied to a soil becomes locked up or fixed in this way. Exactly how much these losses can be reduced by the use of granular phosphates is not known with accuracy; probably the reduction is slight, but it helps.

The traditional method of using fertilizers is to scatter them over the land, either by hand or by machine, and to work them into the top few inches of soil with harrows. That this is not an ideal method has been known for many years, but it is only recently that fertilizer placement has been properly studied and made practicable on the general farm.

For instance, recent trials have shown that a more economical use of fertilizers in growing potatoes is achieved if the compound is broadcast over the ridges just before planting than if the compound is broadcast on the flat before the ridges are opened out. It is proof of what one would expect from bringing the fertilizer closer to the plant. Potato planting machines are now available which not only place the seed tubers but also deposit the fertilizer in two continuous broad bands on either side of the sets. This had been found the optimum position, since to put a concentrated fertilizer actually in contact with the tuber might cause damage to the sprouts.

During the 1930s experiments had been in progress in America, Australia and other countries as well as in Great Britain, with the placing of fertilizers close to the seed of cereals and other drilled crops. It had been proved that considerable economy of fertilizer could be brought about in this way, and a number of different makes of combined seed-and-fertilizer drills became available. In these 'combined' drills the seed and the fertilizer are contained in separate hoppers: in some drills both seed and fertilizer are delivered into the ground through the same tube, while in others two separate spouts are used. There is a saving not only of fertilizer but also of time, for distribution of both

seed and fertilizer is carried out in one operation instead of the two operations of fertilizer spreading and seed drilling. These combined drills proved extremely valuable during the food production drive during the early part of the 1939–45 war, and were particularly instrumental in eking out the very inadequate supplies of phosphatic fertilizer. It proved possible to drill with safety not only phosphatic fertilizers with wheat, barley and oats, but also compound fertilizers as well. The granular fertilizers already described are ideal for combine drilling, since they run very easily without causing stoppages, and at moderate rates do not harm the seed or seedling of cereals.

Not all seeds, however, can be combine-drilled with fertilizers. Leguminous seeds such as peas and beans may suffer reduced germination if fertilizers are placed in contact with them: the same may be said of seeds of the cabbage family and of sugar beet. There is a certain amount of evidence that the best place for fertilizers with the turnip crop is slightly below and to one side of the seed. So far this sort of placement is possible only with special drills which are not available for general use in this country, though they are employed freely in the United States. In these drills the fertilizer and the seed are delivered down separate tubes to separate coulters working at different depths. This type of drill has been used for many years in the Fens for sowing roots. It is interesting to note that a type of combine drill was exhibited at the very first County Meeting of the Royal Agricultural Society (as it afterwards became) at Oxford in 1839. Worlidge in 1669 had described a drill which was in effect a combine drill, because it had an arrangement for depositing guano with the seed.

COLLATERAL READING

An elementary account of the soil is given in *The Soil: an Introduction to the Scientific Study of the Growth of Crops*, by Sir A. D. Hall, completely revised by G. W. Robinson (John Murray, 1945). Comber's *An Introduction to the Scientific Study of the Soil* (Edward Arnold, 1946) has long been a standard work. For a description of methods adopted in soil classification consult *Soils—their Origin, Constitution and Classification*, by G. W. Robinson (Thomas Murby, 1938) and *Good Soil* by S. G. Brade-Birks

(English Universities Press, 1944). A guide, illustrated in colour, to deficiency diseases is provided in T. Wallace's *The Diagnosis of Mineral Deficiencies in Plants* (H.M.S.O., 1943), and its Supplement (H.M.S.O., 1944). The controversy over humus and chemical fertilizers can be followed by reading *An Agricultural Testament*, by Sir Albert Howard (Oxford University Press, 1940), *The Living Soil*, by E. B. Balfour (Faber and Faber, 1946), *Humus and the Farmer*, by Friend Sykes (Faber and Faber, 1946), and *Chemicals, Humus and the Soil*, by Donald P. Hopkins (Faber and Faber, 1945). The last volume gives a list of recent books touching on the subject. *The Rape of the Earth: a world survey of soil erosion*, by G. V. Jacks and R. O. Whyte (Faber and Faber, 1939), should be studied by all who are interested in food production. An account of hydroponics is given by W. F. Gericke in *Soilless Gardening* (Putnam, 1946).

Fertilizers and manures can be studied in Sir E. J. Russell's *A Student's Book of Soils and Manures* (C.U.P., 1946) and E. Vanstone's *Fertilizers and Manures* (Macmillan, 1947). See also *Profit from Fertilizers*, by H. V. Garner and others (Crosby Lockwood, 1945), and Bulletin 35 of the Ministry of Agriculture, *The Use of Lime in Agriculture* (1948). *Soil Conditions and Plant Growth*, by Sir E. J. Russell and others (Longmans Green, 1942) is a standard work.

The Fertiliser and Feeding Stuffs Journal, published fortnightly, gives current information about fertilizers and associated matters.

Chapter Three

CROPS

Need for new varieties—selection—hybridization—Mendel's discoveries—polyploids—quality in wheat—Biffen's experiments—Yeoman wheat—strength of straw—spring wheats—disease resistance—yellow rust—quality and yield in barley—Hunter's experiments—Spratt Archer—Plumage Archer—Scandinavian barleys—autumn sown barley—dual value of oats—hybridization of oats—winter oats—breeding for frit fly resistance—desirability of reducing the number of cereal varieties—yield and quality in potatoes—differences between true seed and tuber—resistance to Wart Disease—hybridization with wild forms of Solanum—sugar beet—selection for sugar—'mono-seed' varieties—dry matter in root crops—mangolds—turnips and Finger-and-Toe disease—kale—testing of crop varieties by the National Institute of Agricultural Botany—seed testing.

If the peoples of the world are to live they must have food, and this means that they must grow sufficiently large crops of different kinds of plants to suit their needs. Crops are much more important than stock, because without plants animals cannot exist. The so-called stock raiser has first to raise his plants, even though they consist entirely of grass, before he can feed his animals. The amount of cultivable land in the world is limited, and much farm soil is already being lost by erosion in North America and parts of Africa and Asia. In consequence of this, and the increase in population in many parts of the world, the necessity for increasing crop production is very real, despite the fact that at times, owing to unscientific methods of distribu-

tion, apparent over-production has led to the spectacular destruction of food to maintain prices. The recent desire on the part of many countries to become as self-supporting as possible, as an insurance in times of war, is another factor.

In an intensively farmed country such as this it is essential that heavy crops should be produced, hence there is a continual striving to obtain better and better crop plants. The breeding of such plants is carried out by commercial seed houses, by private individuals, and by institutions supported, to some extent, by the State. This work, although it will always remain very much an art, becomes more and more scientific every season.

Actually, the science of plant breeding is of very recent growth indeed. Although wheat, for example, has been grown for thousands of years, it was not until the closing years of last century that it was even realized that its flower is self-fertilized. The world had to wait until 1901 before any definite scientific principles governing the art of plant and animal breeding were made generally known.

The improvement of crop plants by selection of likely-looking individuals and their propagation by seed has, of course, been practised from time immemorial. Crop improvement by these means is bound to be slow and to become progressively slower, because it depends upon casual discovery; the more intensively a crop is examined the less and less likely is an outstanding plant to be found. Fifty or sixty years ago it was comparatively easy to select out good plants from a cereal crop, because the average standard was low and the crops were very mixed. But now the average standard is much higher, and the crops are more even, so that improvement by selection alone is scarcely possible. The crossing of two plants, or hybridization, in the hope of obtaining something fresh, has been extensively practised since the latter part of last century, and with some success. But the progeny of such crosses so frequently seemed to 'revert', or 'throw back', to their ancestors in such an inexplicable way that the idea grew up that the offspring of crosses were naturally instable, and that in consequence little was to be hoped for in this line of investigation.

But in 1901 there occurred an event which put fresh life into the plant breeders. It was the republication of a scientific paper written by Gregor Mendel as far back as 1865. For nearly forty years it lay forgotten in the archives of a small Natural History Society at Brunn (now called Brno) in Moravia, and its author had been dead over sixteen years before the scientific world became aware of the principles he had brought to light. The incident provides an extreme example of the lag which may exist between the discovery of a principle and its application to human needs. Mendel explained for the first time that the offspring of hybrids may be expected to appear in definite mathematical ratios in different generations, and that the characters of plants could be regarded as individual entities, for they could be inherited separately. There is no need to go further into the study of Mendelism—explanations can be sought in the books referred to at the end of this chapter—but it is sufficient to say that the stimulus of these rediscovered principles has done a great deal for modern scientific plant breeding. Some of Mendel's statements have not borne the test of time, but of the value of his pioneer work there is no question.

Mendel's work agreed very well with much that was known of the structure and behaviour of the plant cell, and in particular of the cell nucleus. The conception of the chromosomes in the nucleus as the carriers of hereditary qualities became well established in the early part of the present century (see p. 136) and it became possible, for example, to explain why certain kinds of wheat, such as the 'cone' or 'Rivet' wheats, would not cross readily with the common bread wheat: the reason is that the two kinds of wheat have different numbers of chromosomes. There are, in fact, wheat species having two sets of chromosomes (diploid), four sets of chromosomes (tetraploid) and six sets of chromosomes (hexaploid). Generally speaking, one species of plant does not cross easily with another species, or if it does, the offspring is weakly and frequently infertile. But occasionally fertile crosses occur in nature which result in the doubling or even trebling of the chromosomes, and a new 'polyploid' species is borne. There is plenty of evidence to show that many of our

present-day crop plants have been formed from natural crosses of this sort. About 1937 it was discovered that exposure of living plant cells to a weak solution of the drug colchicine causes the number of chromosomes in each cell to become doubled, and this leads to changes in the size and behaviour of the plants. The doubling of the chromosomes also puts into the hands of the hybridist an interesting new weapon, and already new breeds of rye, red clover and alsike clover originating from colchicine treated plants are being tested on a field scale in Sweden and elsewhere. It is too early yet to say how successful these polyploid varieties will be. It is interesting to note also that hybrids have been established by normal methods between certain plants which are usually considered to have rather distant relationship. For example hybrids between wheat and rye, and wheat and wheat-grass (*Agropyron*) have been established in an effort to breed wheats capable of surviving extremely difficult soil and climatic conditions. At the moment these are just interesting novelties and their use to the farmer is uncertain—but the implications of the work are, of course, immense.

One of the first crop plants to benefit from the new study of Mendelism was wheat. Two things influence the value of the wheat crop—yield and quality. British farmers grow almost the heaviest crops of wheat in the world, averaging about 19 cwt. per acre. In Australia and the Argentine the yield is only 6–7 cwt., and in Canada 9–10 cwt. per acre. But the quality of English wheat is, on the whole, inferior to that of imported wheat. By quality is meant the 'capacity to make large, well-piled loaves', and this depends partly upon the starchy material in the grain, but more especially upon the gluten. British wheats are deficient in gluten, and are said to be 'soft' and 'weak'; imported wheats are 'hard' and 'strong'. A two-pound loaf made from 'weak' British wheat-flour gives a loaf with a volume of about 2,000 cubic centimetres only, whilst a similar loaf from Canadian flour has a capacity of over 3,000 cubic centimetres. The opening up of huge wheat-growing areas in America and Australia, and the public demand for a white, spongy loaf, did great damage to English wheat growing, and the acreage

under the crop declined very seriously towards the end of last century.

Biffen, at Cambridge, discovered that the strength or the weakness of a wheat variety behaves in accordance with the rules laid down by Mendel, and this at once opened up possibilities for improving the quality of English wheat. Biffen's first product was a cross between a variety called Red Fife, one of the strongest and best milling wheats, and Rough Chaff, a high yielding, poor quality variety. All the progeny of the first cross were found to be 'hard', and when plants of this generation were grown next year there was segregation into hard and soft individuals: there were approximately three times as many hard-grained plants as weak-grained. Biffen selected some of the hard grains from this generation, and after several years was able to put on the market a new 'strong' variety of wheat which he called Burgoyne's Fife. The fact that the yield of this good quality wheat subsequently proved disappointing does not detract seriously from its historical importance. The raising of this wheat was a landmark in the progress of plant breeding, for it demonstrated the value of Mendel's theory, and encouraged further attempts at building up a good quality, heavy yielding English wheat.

The very pertinent question may be asked—why could not some of the strong wheats from Canada or Australia be grown in this country? Many attempts were made to do this, but they were not very successful economically for two reasons. First, the yield of these imported wheats was much lower than that of English wheats for they were mostly spring wheats, which as a rule yield less than winter-sown wheats; and second, it was found that the strength or quality of the grain progressively diminished with every succeeding season. The climate, soil, and manuring of these islands undoubtedly reduced the quality. There was one exception to this, the variety Red Fife, mentioned earlier. Red Fife maintained its strength under English conditions, but its yield was small.

Biffen decided to make another attempt to graft the quality of Red Fife on to the yield of an English wheat. Numerous

crosses between Red Fife and some of the heaviest yielding native wheats were made, until the number of plants of the second generation amounted to 80,000. Again it was noticed that the bulk of these had the hardness of Red Fife. Of the 80,000 plants some 200 were selected, and two years later these were whittled down to 24. The latter were tested for yield, and the four best selected. At the same time an attempt was made to assess the quality of the grain of the selected varieties, but this was by no means an easy matter because so little grain was available. There was not enough to permit a baking test, so quality was assessed by estimating the nitrogen—it being assumed, with some accuracy, that the higher the proportion of nitrogen the greater the quantity of gluten. The physical nature of the gluten was assessed by the chewing test. This is a very simple test, but it appears to be as reliable as any other yet in common use. Some grains of wheat are chewed in the mouth until the starch has been dissolved away and a sticky pellet of gluten remains. The pellet is then placed in a shallow dish containing water; if the gluten is of good quality for bread-making the pellet retains its shape for some time, whereas a pellet of poor-quality gluten soon disintegrates.

By the fifth generation enough grain was available for a baking test, and it was found that all the four varieties were of better quality than any other English wheat. One of the four was selected and then grown on until in 1916 there was a stock of seed sufficient for general distribution. The new variety was called Yeoman. On good land Yeoman yields as well as almost any wheat, giving 40 cwt. or more per acre in some cases. On poorer land its yield is less satisfactory, despite its strong straw, which permits intensive manuring. It gives a flour of excellent baking quality, capable of making a good, marketable loaf without the admixture of imported flour. Since its introduction, Yeoman has taken its place in general farming as a really good yielding wheat on good, well-cultivated land. From it has been selected Yeoman II, which has an even better quality of grain; baking tests have shown that it will yield a two-pound loaf of well over 3,000 cubic centimetres. Yeoman has recently been crossed with

White Fife by Engledow, and the variety Holdfast thus originated appears to be superior to Yeoman both in quality and yield.

It must not be imagined that the breeding of Yeoman has solved all the problems of the wheat growers in this country. It has demonstrated that high yielding, high quality wheat can be grown on good wheat land, but unfortunately there is not a great acreage of this type of soil in the country.

On many types of soil the high-quality bread-making wheats do not yield so well as wheats which have weaker, softer grain; and since there is no price bonus for quality in wheat, those varieties which will yield well on soils of medium to low fertility will continue to be grown irrespective of the baking quality of their flour. This is not to imply that quality is of no account in the breeding of wheat. Some years ago a number of Scandinavian wheat varieties were imported into this country and gave satisfactory yields. But such great difficulty was experienced by millers in passing the flour of these varieties through the standard sieves that these wheats are no longer recommended for normal English conditions.

In addition to yield and high quality the cereal breeder has to consider other factors, such as resistance to 'shattering', strength of straw, and susceptibility to disease. By shattering is meant the liability of the grain to drop out of the ear as it ripens. This is a matter which has assumed great importance during the last ten years because of the increase in the number of combine harvesters (see Chapter Ten). When self-binders were universally used to harvest wheat, the crops were cut before they reached the dead-ripe stage, and there was consequently little tendency to shattering. But when crops are combined they have to be left as long as possible to allow the grain to dry out, and in the dead-ripe condition some varieties, such as the French types Bersée and Franc Nord, may shatter severely and much grain is lost.

Strength and length of straw have become of supreme importance for two reasons. First, it has been shown in repeated trials that the application of nitrogenous fertilizers greatly increases the yield of wheat (as well as of other cereals). A top

dressing of 1 cwt. per acre of sulphate of ammonia may be expected to give between 2 and 3 cwt. extra grain; double this manurial dressing may increase the yield by about 5 cwt. per acre. But in the wetter arable districts this amount of nitrogen may cause the straw to lodge, or 'go down' as the farmer calls it, which leads to delay in harvesting and also to loss of grain. Consequently only those varieties with straw capable of standing up to appreciable doses of nitrogen are worth considering by the plant breeder. Secondly, the combine harvester demands a rigid straw, and one that is preferably not too long. Varieties like Squarehead's Master and Little Joss have long, comparatively weak straw. Yeoman and Holdfast have more rigid, slighter shorter straw: varieties like Jubilegem, Bersée and Vilmorin 27 have shorter straw still, which is semi-solid and very thick walled.

Another point which has to be taken into account by breeders of wheat is the liability of the grain to sprout in the ear if the weather at harvest is exceptionally wet. This is of importance whether the crop is harvested by binder or by combine. Generally speaking, red-grained wheats are less likely to sprout than are the white-grained wheats. The white-grained Holdfast variety, which is of excellent milling and baking quality, and which yields well and has stiff straw, is very prone to sprout in a wet harvest, and some farmers in the west of the country are not fond of it because of the losses and inconvenience caused by the habit.

For many years prior to the 1939 war there was little interest here in spring wheat because the yield could not compare with that of autumn planted wheat with its much longer growing period. But the introduction of certain Scandinavian and French varieties of spring wheat has altered the position very considerably, for these types are not only heavier yielders than the old varieties, but they have strong straw and ripen very early. They have frequently outyielded autumn wheats grown on the same land and have ripened earlier as well. These types range from Bersée (which can be grown both as an autumn wheat and as an early spring variety) to Atle and Fylgia. Atle is a short, stiff-

strawed variety raised in Sweden; Fylgia, also from Sweden, has not been anything like so successful in the country of its origin as it has over here, and it emphasizes the need for testing out new varieties of crop plants in the country or district in which they are to be grown. Fylgia has given remarkable yields in both light and heavy soils in this country when sown as late as the end of April, and stands well though it has appreciably longer straw than Atle. As a consequence of the introduction of these new breeds the growing of spring wheat has enormously developed in many parts of the country.

The question of disease in crops is of the greatest importance, and quite naturally the farmer turns to the scientist and asks for varieties immune to such and such a complaint. He really does not know how much he is asking, for all sorts of considerations —such as time of ripening, speed of germination, thickness of epidermis, size and number of breathing holes (stomata) in the leaf, chemical nature of the cell sap, etc.—may determine the susceptibility of a plant to a disease. Immunity to one disease may be linked up with susceptibility to another disease, and so on. Nevertheless, progress has been made in breeding disease-resistant plants, and wheat provides an illustration.

There is a very common fungus disease of wheat in this country called Yellow Rust. It takes the form of long yellowish or orange streaks on the leaves and stems during summer, and although it causes few spectacular failures the disease is estimated to reduce the yield throughout the wheat areas by 5 to 10 per cent. Biffen found that susceptibility to rust behaves as a Mendelian character, and armed with this knowledge he proceeded to raise a rust-resistant wheat. About 1908 he crossed a very rust-resistant wheat from Russia, called Ghurka, with Squarehead's Master. The offspring were all susceptible to the disease. The second generation, that is, the plants grown from seed formed from these self-fertilized, susceptible plants, included both susceptible and immune individuals. Approximately three plants out of every four were susceptible, but Biffen knew from Mendelian principles that the immune plants would retain their immunity. He selected from these immune individuals a form

which seemed to have good cropping powers, and propagated it under the name of Little Joss. This variety is immune to Yellow Rust, and unlike Yeoman does well on light soils. Its quality is not so good as that of Yeoman, and its straw is only moderately strong: it can be sown either as a winter wheat or an early spring wheat.

But unless a breeder is breeding specifically for resistance to a particular disease, disappointment may follow the introduction of a variety which appears in most respects to be very satisfactory. An example of this is provided by the wheat variety called Desprez 80. This wheat was introduced from France at about the time the great war-time food production drive was beginning. It has very stiff, short straw, and it gave very heavy yields of a rather coarse soft grain, and became extremely popular. But after the first few seasons it became devastated by Yellow Rust, so much so that it has now completely dropped out of cultivation in this country.

On many of the lighter arable farms in England barley is a more important crop than wheat. The barley grower aims at obtaining a sample which will be purchased by a maltster or brewer, because a malting sample fetches very much more per hundredweight than barley used for feeding to stock. Here, as in the case of wheat, there are two distinct problems—those of quality and yield. Until quite recently malting barley was purchased entirely on its appearance. The buyer looked for a dry, uniform sample having, amongst other things, a pale lemon colour and a very finely wrinkled 'skin', together with a white, mealy interior. He knew that if his eye was satisfied with the sample, his ale would be clear and pale and would keep, but he did not know why. He had to wait until 1902 before Beaven supplied the reason. Beaven showed that the appearance of a good malting barley is related to a low percentage of nitrogen; bad malting barley has a relatively high proportion of nitrogen. Generally speaking, a good malting barley has less than 1·5 per cent nitrogen, calculated on the dry matter of the grain. It was discovered later that some varieties of barley naturally produce grains low in nitrogen content; but at the same time it was also

evident that the weather, particularly towards harvest, can influence the proportion of nitrogen to a considerable extent.

The problems facing the plant breeder were therefore very complicated. He had to raise a barley naturally low in nitrogen, capable of giving a good yield per acre, possessed of a stiff straw, and able to ripen rapidly. The earliest large-scale scientific attempt in the British Isles to improve barley was begun by Hunter in Ireland about 1900. The first thing was to collect and examine as many varieties as possible, and study their suitability both to the farmer and brewer. Of the numerous types, a variety called Archer seemed the most likely. This is a narrow-eared barley of high quality, but rather weak straw and a tendency to lateness in ripening. A selection was made in 1904 of a promising plant of Archer, and this variety by 1910 was giving a yield of approximately 1½ cwt. more per acre than the average for Ireland. It is interesting to note here that the Danes, in their experiments carried out from 1883 to 1903, also fixed upon Archer as being the best variety. Their type, however, was called Prentice—it was derived from an Archer barley imported from England.

But the weakness of Archer straw was a great disadvantage, so Hunter crossed his improved Archer I with a variety called Spratt having a very stiff straw but inferior quality grain. From the progeny of this cross was selected a barley which seemed to combine the quality of Archer and the straw of Spratt. It is a narrow-eared type like Archer, but has a brighter grain, is earlier in ripening, and yields more. Grown both on light and heavy soils its nitrogen content is less than that of Archer. The new variety was named Spratt-Archer. It was extensively tested out between 1919–23, and in a very few years it ousted almost all other varieties on the light barley soils of England.

Archer barley, however, is not suited to soils of high fertility, especially those in the west of England. In these districts broad-eared barleys have been much more successful, particularly since the introduction of the Goldthorpe variety about 1890. Goldthorpe gives a very good malting sample but has a straw which becomes brittle below the ear just before harvest. Losses through the breaking off of the ear may be considerable. To overcome

this serious disadvantage Beaven in 1905 made a cross between a type of Goldthorpe called Plumage, and Archer, which has a particularly short 'neck', or portion of straw between the ear and the first sheathing leaf. From this cross originated the variety called Plumage-Archer, which is a broad-eared barley capable of yielding large crops of good quality grain, and having the strong neck of Archer. This soon became the most widely grown of the broad-eared barleys.

It is really very remarkable how quickly Spratt-Archer and Plumage-Archer came to share between them about 80 per cent of the barley growing area in this country, to the great financial benefit of the industry. It is a thing which is not paralleled in any other cereal. Recently there has been a developing interest in certain Scandinavian barley varieties (such as Abed Kenia, Abed Maja, Freja, etc.) because of their greater strength of straw and earlier ripening. There is not a great deal of difference in the yields of these Danish barleys and Spratt-Archer, taking them over a series of years: the Danish varieties are not so well liked by maltsters because they have a higher nitrogen content and give less 'extract' when processed for brewing.

An interesting development in barley growing has taken place during the last decade or so, namely the autumn sowing of malting varieties. Certain types of barley, the six-rowed types, have for long been planted in autumn. They are winter hardy, but give grain which is used for feeding or industrial purposes instead of for malting. Some farmers on light land in the south of the country have begun to plant Plumage-Archer and Spratt-Archer in late autumn, and after mild winters have harvested good crops. The advantages of the system are the avoidance of drought in dry springs, and the better spread of farm work at planting and harvest. But the spring barleys are not truly winter hardy, and severe winters play havoc with them if autumn planted. Recently a two-rowed winter hardy barley called Pioneer has been bred by Bell at Cambridge. It is a cross between Spratt-Archer and a winter hardy German variety, and it has survived all the winters since 1939 with success; it can be recommended with confidence as a malting barley for winter planting.

Oats have given the plant breeder a double problem, because unlike other cereals, the straw of oats may be just as valuable as the grain. The grain of oats is used chiefly as a food for farm animals and horses, though a considerable amount is consumed by human beings in the form of porridge and oatmeal products. The straw of oats is fed in the long state or is chaffed up into small pieces and fed to stock. In the more northerly farming districts the feeding value of oat straw is very high, and it is claimed that a bullock can be fattened upon nothing else but oat straw and turnips. Oats, therefore, constitute a dual-purpose crop. On light soils and in hill districts the straw may be more important than the grain; on good soils the position may be reversed. Consequently there are very numerous varieties of oats, all of them supposed to have special advantages in certain districts and on certain soils.

The raising of new varieties of oats by hybridization did not start until about 1890. The outstanding varieties up to then—Sandy, Potato, Hopetoun—were chance discoveries. The 'Fellow' oats, such as Early Fellow and Long Fellow, were selections made as the result of systematic searches through growing crops. The first hybrid oat to be marketed was raised by Dr. John Garton, of the firm of Gartons Ltd., Warrington. It was introduced in 1892 under the name Abundance and was a cross between White August and White Swedish.

The variety Marvellous, also raised by Gartons, illustrates very well the complexity of the task facing the would-be plant improver. Marvellous was derived from a cross between a white-grained oat and a grey-grained oat. The former in its turn originated in a cross between the Wild Oat and Grey Winter; the latter was a hybrid between the Wild Oat and Goldfinder (a variety bred by Gartons in 1901). The pedigree of Marvellous is, therefore:

$$\underbrace{\underbrace{\text{Wild Oat}\quad\text{Grey Winter}}_{\text{White grained oat}}\qquad\underbrace{\text{Wild Oat}\quad\text{Goldfinder}}_{\text{Grey grained oat}}}_{\text{Marvellous}}$$

Marvellous was a selection made with the idea of obtaining an oat which would be winter hardy, and it was put on the market in 1921 for winter sowing. Most oats, of course, are sown in spring, and an improved winter variety was very much required. For some seasons after the introduction of Marvellous the winters were mild and the variety did very well. Then came one or two severe winters, and Marvellous was found not to be truly winter hardy. As a spring oat Marvellous often does well, though it has been largely superseded by newer varieties; but this case does show how the plant breeder may be led to false conclusions because of slight changes in climatic conditions.

Modern varieties of spring oats originate both from hybridization and from selection. The well-known Victory oat resulted from a slection of the Probsteier variety at the Swedish Plant Breeding Station at Svalof, and was marketed in 1908.

It was a considerable advance upon the variety Abundance already mentioned, and has been widely used in the hybridizing of other varieties though it has been superseded to a large extent on good land by Star, Onward and Eagle. Milford (or S.225) has for one of its parents S.172, and inherits its short stiff straw. There is indeed a very large number of spring oats, varying from the weak strawed, thin grained, poor yielding types like Ceirch-du-bach and Radnorshire Sprig grown on infertile soils at high altitudes in wet climates, to heavy yielding types such as Star and Eagle suitable for better soils in more favoured climates.

Considerable improvements have been made in winter oats by the plant breeders. Until quite recently the only variety which could be relied upon to stand a moderately severe winter was Grey Winter, which is notoriously weak in the straw, with a rather poor grain. Crosses of Grey Winter with various spring oats have given us Picton, S.147 and S.172. Picton, which was bred at Cambridge, is a hardy white grained oat suited to the dry conditions of the eastern side of the country. S.147 is a good yielding, strong strawed winter oat from the Welsh Plant Breeding Station, suited to the moister conditions of the western side of the country. S.172 is a dwarf oat with very stiff straw, specially bred for very fertile soils upon which most oats are likely to 'go

down' very badly: its yield on average soil is likely to be 10 per cent below that of S.147 or Picton, but with the extended use of the combine harvester S.172, on account of its excellent standing power, is becoming popular in districts for which it was really not intended.

Hybridization of oats is being practised now, not only with yield and quality as the immediate object, but also in an attempt to overcome the ravages of the Frit fly. This is an insect which in spring lays its eggs close to oat plants, and its maggot lives on the juicy growing plant. The main shoot of the plant is destroyed, and the side shoots either develop too late to flower or else give a much reduced yield. It has been found that certain oat varieties, Eagle for example, are much less susceptible to attack than others, and attempts are being made to combine this resistance with good yielding capacity and good grain. Similarly, certain varieties are more resistant to root eelworm than others. Picton is more resistant than S.147 or S.172, and so on.

If the best use is to be made of the farmland devoted to arable crops it is very necessary that only the most profitable varieties of cereals shall be grown. Not long ago over 100 different varieties of wheat and barley were listed in seedsmen's catalogues: when all allowances are made for local conditions, it is obvious that this is an excessive and unnecessary number, not only from the farmer's point of view but also from that of the seedsman and miller. The seedsman is inconvenienced through having to stock a large number of varieties, and the miller is unable to obtain large bulk supplies of wheat of uniform type and condition because of the variation between different individual varieties. Many of the existing varieties have no special virtue to commend them, and their continued use is an embarrassment to growers, merchants and millers. The National Institute of Agricultural Botany, in consultation with millers, bakers, seedsmen and growers, has recently published a list of some twenty recommended varieties of wheat, classifying them into bread-making, biscuit-making, and non-baking types. These wheats have all some special feature or features to recommend them, and farmers are advised to make a choice from the list unless they know

definitely that some other variety is more suited to their locality and conditions. A recommended list of barley and oat varieties has also been drawn up. If this plan can be followed there is a prospect of an advantageous reduction in the number of varieties offered to farmers during the next few years. The list of recommended varieties, of course, is subject to periodical revision, and varieties may be removed from, or added to the list.

Next to the cereals the potato is the most important crop grown here for human consumption. The area under the crop in 1948 was over one million acres, and the yield amounted to 8,480,000 tons. A very great deal of scientific investigation has gone into the improvement of this crop, though much remains to be done, especially with regard to the breeding of varieties resistant to Blight and Virus diseases (see pp. 114–19). Present-day potatoes are much superior to the small, irregular, highly flavoured potato of a century ago.

The improvement of the potato really dates from the years of the great famine in Ireland (1845–7), when at least half of the potato crop was destroyed by the Blight fungus (*Phytophthora infestans*), causing widespread misery and starvation. Determined efforts were made to find a variety immune to this disease, and they are still being made, but so far with indifferent success. Until such a variety is found, reliance will have to be placed on protective spray fluids such as Bordeaux and Burgundy mixtures (p. 114) or the new copper colloids.

Since the middle of last century, too, a lot of attention has been paid to other aspects of the potato crop. A reasonably heavy yield is a *sine qua non*, but yield alone does not mean a satisfactory financial return per acre to the grower. Nowadays the public demands a quality potato. The tuber must be of a medium size, preferably of an oval or kidney shape; very big and very small potatoes are of little market value, for obvious reasons. The 'skin' of the tuber must be thin, and its 'eyes' (which are really collections of buds) must be few, and shallow; otherwise there is considerable wastage in peeling. The flesh must be white, for the public will not buy a yellow-fleshed potato despite its greater feeding value. It must cook to give a bulky, light flour

which does not readily discolour. Chip potato merchants require special characteristics in their potatoes. Unless the tubers themselves have these qualities, the variety is not worth growing, because merchants refuse to buy. But in addition the farmer must have early varieties which will catch the profitable market just as the over-wintered supplies of potatoes are giving out, and he needs varieties which will resist insect and fungus enemies.

The would-be improver of potatoes is in a rather curious position. In the first place, it must be clearly understood that the ordinary potato as eaten is just a swollen piece of underground stem. When these stems, or tubers, are planted they are often spoken of as 'seed', but they have nothing in common with true seed, which can be formed only from a flower. In the ordinary course of cultivation a potato variety propagated by tubers retains its characteristic shape, colour, structure, and so forth, indefinitely. Its cropping power may suffer, or 'degenerate', on account of virus disease, but not its general nature. On the other hand, potatoes which are reproduced from the true seed, the seed within the 'apple' or berry formed from the flower, do not 'come true'. They split up into a number of different forms, some similar to, others very different from, their parents. Further, very few commercial potato varieties form perfect flowers. In some the flowers are seldom found at all, in others the flowers develop, but drop off before they mature; others again form flowers but no pollen. The choice of parents for hybridizing experiments is consequently limited, and the breeder must know his varieties very thoroughly before he begins operations.

Whilst it is an easy matter to cross two fertile varieties of potato and obtain a large and diverse progeny, the selection of the most suitable of the latter demands knowledge, careful observation and skill, and a ruthlessness in the destruction of unwanted types. It is not a difficult matter to select for shape, thinness of skin, paucity of eyes, and other characters of the tuber, and it is only a shade less easy to assess cropping quality. It is quite easy to choose the varieties resistant to wart disease and blight (but not those resistant to virus diseases) and numerous new potatoes of a promising kind have had to be scrapped

when they have been found to be highly susceptible to either or both of these diseases. On the other hand, once the selection has been made, the breeder does not have to worry as to whether his new variety will come true or will 'revert', after the manner of cereal introductions; he knows that so long as it is propagated by tubers it will retain its characteristic features.

Nowadays, it is essential that new potato varieties should be immune to wart disease (see p. 112). One of the most consistently successful breeders of immune potatoes was Mackelvie, living in the Isle of Arran, situated off the west coast of Scotland only a short distance by steamer from Glasgow. Ally, Arran Banner, Arran Pilot, Arran Consul, Arran Victory, Arran Crest, Arran Chief, Arran Comrade, are amongst the best known. Findlay, also in Scotland, has produced the famous immune varieties—Majestic, Catriona, and Di Vernon, and the non-immune Up-to-Date. Clark, in Northern Ireland, is responsible for Ulster Supreme, Ulster Chieftain, Ulster Premier, etc.

Up to the present, new varieties of potato have originated from the crossing of older cultivated varieties, and the various weaknesses from which the crop suffers, such as susceptibility to blight, virus diseases, frost and so on, have been perpetuated. From 1926 onwards there have been several visits to South America by scientists whose object has been to discover wild forms of *Solanum* which could be used in potato hybridization work. Many of these wild species are being grown and intensively studied in the Commonwealth Collection of Potato Varieties at Cambridge, where there are about 2,000 specimens, representing 200 species falling into five groups according to the number of somatic chromosomes, namely 24, 36, 48, 60 and 72. Some interesting facts have already been discovered. A variety, *S. demissum*, is resistant to blight, while *S. acaule* has haulm which will withstand eight degrees Centigrade of frost. Certain wild forms have a considerable resistance to the Colorado Beetle. Other types have more starch, or more nitrogen, than commercial varieties. Some have no dormancy period (i.e. their tubers can sprout almost as soon as they are harvested) and so on. The problem is to combine resistance to disease or frost

with satisfactory yield and eating quality: a certain amount of success has already been achieved, but the possibilities are tremendous.

Sugar beet is another important crop in many parts of England; in 1948 over 390,000 acres were devoted to the crop, and 4,249,000 tons of manufactured sugar were made from the roots. Not only is the crop itself a valuable one on account of the cash returns for the roots themselves, but it is important because of the employment it provides for agricultural workers, casual labourers in the field during the growing season, workers in the beet factories, transport workers, and so on. The high standard of cultivation demanded by the beet is also a national asset. Beet tops, moreover, are a valuable food for sheep and cattle, providing about as much fodder as a crop of turnips.

In England the beet sugar industry dates from about 1920, though there was a factory working at Cantley in 1912. In Europe the industry started about 1800. The sugar beet is a kind of mangold in which the proportion of sugar has been greatly increased by careful selection throughout the last 100 years. It is derived from a wild plant commonly found along certain coastal districts in Europe; some of these wild beet have a very high percentage of sugar, as much as 20 per cent, but their roots are small, tough, and badly shaped. The first real attempt to improve sugar beet was made by Achard in Germany towards the end of the eighteenth century. He picked out from a large number of forms a type with a long, tapering, white-fleshed root, which is the sort in general cultivation to-day. His work was extended by Louis de Vilmorin in France. To make sugar beet a profitable crop it was necessary to do three things—to raise the percentage of sugar in the individual root, to increase the weight of roots grown per acre, and to make the roots easy to lift, because the early types were almost entirely buried in the ground, like parsnips. These improvements have been brought about almost entirely by selection.

To increase the sugar content only those roots having much sugar were propagated by seed. At first the concentration of sugar was determined by immersing the root in salt solutions of

various strengths; those roots rich in sugar sank, while the less rich floated. This was a very crude method, and in 1862 a method of estimating the sugar percentage by means of the polariscope was introduced. In this method a beam of light is caused to shine through a long narrow tube containing a known quantity of beet juice; the beam of light is deflected in accordance with the density of the solution, and it is then a simple matter to calculate the sugar percentage in the whole root. It is not necessary to examine all the root; an instrument called a borer is thrust through the root in one or two places, and cylinders or 'cores' of tissue are extracted. By intensive selection throughout the last fifty years the average yield of clean washed beet has been raised to about 12 tons per acre, and the sugar percentage to 15–18 per cent, whilst in addition a more upstanding, less deeply rooted form has been evolved, much easier to lift than earlier types.

Sugar beet is naturally cross-fertilized, and this makes the work of the plant breeder very difficult, much harder than in the case of cereals. As already explained, the cereals are self-fertilized, so that there is very little risk of crossing with undesirable plants, and a variety once introduced remains true, barring accidents. It is, however, impossible to maintain a true variety of sugar beet, because of its habit of cross-fertilization. Sugar beet will even cross-fertilize with mangolds, and for this reason raisers of sugar beet varieties take great pains to ensure that no mangolds are allowed to flower within about three miles of their best seed crops.

The modern method of breeding sugar beet is first to select 'mother' roots having desirable features; each plant the following season (for sugar beet is a biennial plant) is covered with a canvas or silken bag to keep out foreign pollen, and the individual flowers on this plant are allowed to fertilize amongst each other—it is a form of 'selfing'. The progeny of the seed thus formed are grown separately, and their sugar and other characteristics carefully analysed. If an individual plant thus tested is found to be good, it is crossed with another plant having similar characteristics, and the seed grown on for distribution. The idea

of the 'selfing' is to study the constitution of the individual plants, but in doing this the vigour of the plants is much reduced, and only a small amount of seed becomes available. The controlled crossing of two approved plants restores vigour and powers of seed production.

Selection is also necessary to prevent 'bolting', i.e. the production of seed stems during the first year of growth. The bolting characteristic has been shown to be a Mendelian character, but so far the Mendelian theory has been of little use in the improvement of the crop.

Sugar beet is setting both plant breeder and engineer a very pretty problem. It is now well understood that to obtain maximum yield of sugar per acre the plant population must be high, somewhere in the region of 25,000 or more plants per acre. To obtain this population a fine, firm tilth is essential, the seed must be evenly sown both as regards distance and depth, and the germination must be high. It so happens that the natural 'seed' of sugar beet is a cluster of true seeds united by a woody material, and there may be from two to six seed germs per cluster. This leads to difficulties in singling the seedlings, resulting in loss of time and extra labour costs. One obvious way out of the difficulty would be to breed sugar beet varieties with only one seed in the cluster, and indeed this has been attempted in more than one country during the past forty-five years. In America, naturally occurring 'mono-seed' wild species of beet have been crossed with cultivated varieties, but the hybrids have been relatively sterile: the propagation of certain individual plants in which there is a large proportion of clusters having only two germs is another line of approach.

Meanwhile, also mainly in America, the engineering side of the problem has been tackled from two angles, those of splitting the natural seed into particles containing only one germ, and of drilling these single seeds with precision. The subject is discussed further on page 207.

Although turnips, swedes, and mangolds occupied only 660,000 acres in 1948 they are still very valuable crops. They, together with such things as kale and cabbages, form the so-called

'roots' which are fed to sheep, dairy cows, and fattening bullocks. The present-day turnip and mangold are much better shaped, and yield more heavily, than those of last century. Until recently selection was practised almost entirely for appearance and size. The farmer likes to have a well-shaped root and he likes a big crop, not realizing that the larger the root the higher the proportion of water it contains. As it is, a white turnip may contain 91 to 92 per cent of water; that is, a farmer carting 100 loads of turnips from a field may be carrying ninety-two loads of water and only eight loads of solid matter.

It sometimes happens that a mangold with a high dry-matter content is not very pleasing to look at and therefore fails to become popular. Such an example is Kirshe's Ideal, which in trials and in farm practice has been shown to yield up to half a ton or more dry matter per acre than more popular, better-shaped varieties. A well-shaped, well-coloured mangold with a very high dry-matter content is the recent Danish selection called Barres Otofte No. 9.

Mangolds and sugar beet have been intercrossed to give the so-called 'half-sugar' strains, which resemble the mangold in shape and size. Their real place in English farming has yet to be determined. Fodder beets, which are popular in Europe, resemble sugar beets, and despite their very high dry matter they have not yet found favour in this country: one reason is that they are not so easy to lift as mangolds and turnips.

The Danes were the first to realize the need for quality in 'roots', their investigations beginning about 1883. They found that 1 lb. of the *dry* matter of turnips is equal in feeding value to 1 lb. of barley, and it became obvious that what matters in turnip growing is not the gross yield of the roots, but the quantity of dry matter per acre. With this ideal before them, the Danish investigators began to select plants having a good dry matter analysis combined with favourable yielding capacity; they gradually discarded the inferior strains and encouraged farmers to grow the new types.

Turnips and mangolds behave very similarly to sugar beet, in that they are naturally cross-fertilized. It is consequently very

necessary to keep seed crops of these plants well isolated. They are frequently grown in small patches surrounded by large areas of potatoes or cereals. It is also impossible to keep turnips and mangolds genetically pure in the way that it is possible with cereals; there is bound to be some variation in the plants of any variety of turnips because of this cross fertilization, but it is the business of the plant breeder to keep this variation down to a minimum by continued selection.

Turnips and swedes may suffer severely from a fungus which causes Club-root, or Finger-and-Toe disease. Affected roots become distorted, knotted, or swollen, and rot away. Recently, attempts have been made to select strains of turnips resistant to this disease, and with some success. Varieties such as 'Bruce' and 'Wilhelmsburger' are much less susceptible to Finger-and-Toe than most other varieties, and they also resist another fungus disease, 'Mildew', to a considerable degree. Unfortunately, they do not yield as heavily as susceptible varieties, but they can, and do, give reasonable crops on land which would not grow other varieties.

The introduction of turnips, and much later mangolds, into British agriculture revolutionized and vastly stimulated the industry, but for many years the acreage devoted to these crops has been declining. There are several reasons for this decline, one of the most important being the cost in manpower and money of growing, harvesting and using the crop. Another is the rise in popularity of alternative crops like kale. Thousand-head kale has been known to farmers for many years, but marrow-stemmed kale is scarcely half a century old so far as use in this country is concerned. It is only quite recently that the protein producing properties of marrow-stemmed kale have been realized. A good crop of this kale will produce more than twice as much crude protein per acre as an average crop of beans or peas; and over four times as much as a crop of mangolds, and it is also rich in carotene (see p. 211).

The realization of these facts is causing more and more farmers, especially dairy farmers, to plant kale as a substitute for roots. Kale is much simpler to grow, needs less labour and

acts as a smotherer of weeds. With the aid of the electric fence (page 215), it is possible, on suitable soils, to fold cattle upon kale very economically, taking the cattle to the crop instead of the crop to the cattle. Unfortunately kale is not truly winter hardy, and deteriorates in the field from December onwards. To avoid this loss of nutrients, and also to eliminate the unpleasant work of cutting and carting kale in wet or frosty weather, some farmers now ensile their kale in October: kale silage is very easily made, for if it is chopped up mechanically it can be 'blown' into any convenient container (or merely left in a heap on the ground) where it stores remarkably well without further attention (see p. 185).

There is no point in putting new varieties of crop plants upon the market unless they are superior to existing varieties. Large-scale testing of cereal, root and potato varieties is being carried out by the National Institute of Agricultural Botany, which has its headquarters at Cambridge and numerous sub-stations dotted about England and Wales. At these centres crop varieties are tested with all the careful precautions demanded by statistical workers. The information thus collected enables reliable recommendations to be made concerning the most profitable varieties for the various districts. Since 1946 this work has been extended in co-operation with the National Agricultural Advisory Service.

In order to obtain good crops the farmer must be able to buy seed from good strains or varieties of farm crops. He must also be able to rely upon the purity and vitality of the seed that he buys. As little as forty years ago a great deal of rubbish was being offered for sale to farmers as farm seeds. Sometimes one kind of seed was substituted for another, mixtures and adulterations of seeds were quite common, there was frequently a high proportion of weed seeds, and often the capacity for germination was very low. The reputable seed firms, of course, had been guaranteeing the quality of their seeds for a long time prior to 1920; this was the date of the Seeds Act, a piece of legislation which compelled all sellers of seeds to disclose certain vital information about their wares. Two of the most important facts

which have to be stated under the provision of this Act relate to the purity and germination of seeds, and their determination is a matter of routine scientific tests. The detection and recognition of impurities in samples of seed demand much experience, and for estimating germination capacity in the laboratory a variety of apparatus is necessary, though in essentials the test merely consists of putting the seed in warm, moist conditions and counting those that germinate in a given time. The official duration of the test varies with different varieties of seed, but is usually from ten to twenty-eight days. Scientists have often wished for a more rapid method of estimating the germination capacity of seed, and very recently a promising technique has been developed for certain seeds, especially cereals. The seeds are soaked in water overnight to start the chemical processes of germination and are then cut in two and soaked for three to four hours in a 1 per cent solution of triphenyltetrazolium. If the embryo is alive it stains red, but a non-living embryo is not stained or is only very incompletely stained. The reason is that the tetrazolium salt is chemically reduced on coming into contact with the reductase enzyme system of a living embryo which has been stimulated into activity by the absorption of water. There seems to be good agreement between this rapid method and the standard germination methods, especially if the germination of the seed is high; but the system is so new that much more investigation of it is necessary and certain seeds, such as very small seeds and those of brassicas, are not suitable for the method of testing.

Another interesting application of science to seed testing is concerned with the rye grasses (see p. 74). Two species of ryegrass are widely used in farming, a short-lived type called Italian ryegrass, and a long-lived type called perennial ryegrass. In nature the seeds of these two species are easily distinguished because Italian ryegrass possesses at its tip a long bristle, or awn, which is not present on the seed of the perennial species. Unfortunately the bristle of Italian ryegrass is often completely broken off, and it is then almost impossible to say to which species the seed belongs. In 1929 a method of identification was devised using ultraviolet light. Seed is germinated upon white filter paper, and when

the rootlets are well grown an inspection is made under screened ultra-violet light. Those portions of the paper adjacent to the rootlets of Italian ryegrass exhibit a bright bluish fluorescence, but no fluorescence appears around the rootlets of perennial ryegrass. This test is not an infallible one, but it is a useful additional aid in determining the genuineness of a sample of ryegrass.

COLLATERAL READING

The technique of breeding plants, mainly from the horticultural viewpoint, is described by W. J. C. Lawrence in *Practical Plant Breeding* (Allen and Unwin, 1939) and the underlying principles are given in *The Elements of Genetics*, by C. D. Darlington and K. Mather (Allen and Underwood, 1949). An American book, *Breeding Crop Plants* (McGraw-Hill, 1942) can also be consulted. A survey of crop plants and present trends in breeding them is given by G. D. H. Bell in *Cultivated Plants of the Farm* (C.U.P., 1948). Some indication of the work involved in the improvement of crop plants is provided by E. S. Beaven in *Barley: Fifty years of Observation and Experiment* (Duckworth, 1947): see also *Wheat in Great Britain*, by John Percival (Duckworth, 1948). The astonishing history of the potato and its influence upon civilization is described by Redcliffe N. Salaman in *The History and Social Influence of the Potato* (C.U.P., 1949). Other books on the subject are *The Potato in Health and Disease*, by Tatham Whitehead, T. P. McIntosh and W. M. Findlay (Oliver and Boyd, 1945), and *The Potato*, by W. G. Burton (Chapman, 1948).

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The Journal, interim reports and leaflets published by the National Institute of Agricultural Botany, and the reports of the Welsh Plant Breeding Station, give valuable information on all important farm crops.

Chapter Four

GRASS AND PASTURE PLANTS

Suitability of British climate to grass—temporary and permanent grass—introduction of forage plants—early difficulties in forming permanent grassland—perennial ryegrass—development of indigenous types—the Welsh Plant Breeding Station—cocksfoot—timothy and meadow fescue—importance of clovers—fixation of nitrogen—red clover—wild white clover—Cockle Park discoveries—S.100 and New Zealand white clover—seeds mixtures for grassland—simple versus complex mixtures—ultra simple mixtures—nurse crop—management—ploughing up of old turf during 1939–45 war—the grassland survey—technique of reclamation—depth of drilling seeds—growing grasses for seed—chemical composition of grasses.

The climate of these islands is such that grasses, clovers, and other plants found in grassland grow extremely well. The rainfall is evenly distributed throughout the year, droughts are not common, and the frosts of winter are usually not sufficiently severe to do serious damage to the herbage. No other country in the world, with the exception of New Zealand, enjoys climatic conditions so favourable to the production of grass. Our best grassland is consequently very good, but at the same time there are, even after the experiences of the 1939–45 war, many thousands of acres of grass in very poor condition indeed, due to mismanagement, understocking, and ignorance of new and improved methods of treatment.

Before explaining modern ideas about the treatment of grass-

land it is necessary to be a bit more precise about the term 'grassland'. Broadly speaking there are two types of grassland, rotation grass and permanent grass. Rotation grass is an essential part of most forms of arable farming, and it is of a very temporary nature; it is, indeed, frequently referred to as 'temporary' grass. In the old Four Course Rotation, or Norfolk shift, the sequence of cropping is: 1st year Wheat; 2nd year Roots; 3rd year Barley; 4th year Clover. The clover and grass seeds are sown with the barley in the third year, and when the cereal has been removed after harvest the clover and grasses can, if desired, be lightly grazed that winter, cut for hay in the early summer following, and possibly grazed again before being ploughed under in preparation for the wheat crop which is usually sown in October or November.

The clover crop consequently occupies the land for about fifteen months, during which time a certain amount of fertility accumulates in the soil, due to the formation of a mass of grass and clover roots and the special action of the clover in accumulating nitrogen from the air. But in many districts it is found preferable to allow the 'seeds' to remain down for two, three, four, or more years before ploughing them under. Such leys, although they may be of long duration, still form part of an arable system of farming. From the very start it is the intention of the farmer to plough them up eventually and crop the land with something else.

Permanent grassland, in the sense of the word usually accepted to-day, is never ploughed, or is ploughed at such enormous intervals of time as to amount to the same thing. There are many different kinds of permanent grassland; at one extreme there are large areas of poor natural hill grazings in the north and west, and at the other extreme the very rich and highly prized fattening pastures of Leicestershire and other counties. On the former a sheep may need to roam over many acres in its search for sustenance, whilst in the latter a full-grown bullock may, without any extra feeding, find enough nutriment on one acre to make it grow fat. There are the rich salt marshes round our coasts and the thin dry pastures of the Downs, the spongy

grasslands on peaty soils and the acid grasslands in the neighbourhood of large industrial smoky areas. Variety of this sort makes it difficult to deal with the problem at all concisely.

Much of the permanent grass is used as pasture, that is, it is grazed by animals throughout the seasons. Some of it is meadowland, that is, it is shut up for hay from May to July, though it may also be grazed at other times of the year. In other cases hay crops may be taken at irregular intervals.

Modern science has a great deal to offer the farmer whose living depends partly or wholly upon his grassland, because tremendous strides have been made in the improvement and management of herbage plants during the last thirty years. The new knowledge is well appreciated in scientific circles and by certain progressive farmers, and it is filtering through very rapidly into general farming.

In the first place let us consider the separate plants which constitute the herbage of grassland. It is very remarkable how few species of grasses and clovers (using 'clover' in a wide sense) are used by farmers. About 130 different species of grass are found in this country—only half a dozen are at all widely used on the farm. Not more than four or five of the numerous clover tribe are sown to any large extent in seeds mixtures. The most useful grasses, experience tells us, are perennial ryegrass, Italian ryegrass, cocksfoot, timothy, and meadow fescue; the most widely used clovers are red clover, white clover, alsike clover, trefoil and lucerne.

Prior to the beginning of the nineteenth century it was not at all easy to get suitable supplies of seed of these grasses and clovers, or indeed of any grasses and clovers except the ryegrasses, red and white clover. Clover seed was imported from Flanders and sown by itself as early as the middle of the seventeenth century, and perennial ryegrass was obtainable in a more or less pure condition at about the same time. A century later, that is, about 1760, cocksfoot seed was imported from Virginia and timothy seed from the States. During the early part of the nineteenth century communications improved, steam as a source of power became available, and grass and clover seeds could be

obtained much cheaper, and also in a purer state, than at any previous time. These dates are important, for it is necessary to remember that the practice of forming long duration or permanent grassland from the sowing of seeds mixtures, compounded from specified amounts of pure seeds, is not much more than 180 years old. The much commoner plan was to use sweepings from hay lofts and barns.

Naturally, these sweepings, like impure samples of commercial seeds, contained many weed seeds and were of poor germination quality. The formation of good permanent grass was consequently a chancy and a lengthy business, and a good pasture once formed was not a thing lightly to be broken up again. Hence there grew up a great respect for a piece of old turf, which towards the end of the nineteenth century developed into an uncritical adoration. Old pasture became almost sacred in the estimation of landlords, and severe financial penalties, amounting in some cases to a fine of £50 per acre, were held over the heads of incoming tenants lest they should plough out this old turf. More will be said about this aspect of grassland. Meanwhile it is necessary to consider how modern investigation has improved some of the plants required in grassland formation.

The first grass ever to be cultivated alone for its seed was perennial ryegrass. It was grown in Oxfordshire early in the seventeenth century, and found its way later to all the temperate countries of the world. The merits of the grass, such as its rapid germination, quick establishment, palatability, yield, and so on, led to the development of considerable seed-growing industries in Ayrshire, Northern Ireland and elsewhere. Certain types of perennial ryegrass were found to give seeds that were larger and had less husk than others; size and weight came to be regarded as the principal things to look for in perennial ryegrass seed, and buyers were encouraged to buy perennial ryegrass of high bushel weight regardless of the type of plant to which this seed would give rise.

The result of this policy of insistence upon heavy seeds was the losing sight of the main purpose for which perennial ryegrass is grown—namely, the production of leaves. Continual cultivation

for seed and yet more seed led to an unconscious weeding out of the leafy types with comparatively few flower stalks, and a concentration upon plants with many flowering stalks and relatively few leaves.

The consequence was that towards the end of last century perennial ryegrass began to get a very bad name amongst intelligent agriculturists, especially for permanent grass. Yet at the same time careful examination of the herbage of good pastures in different parts of the country showed that perennial ryegrass and a dwarf form of white clover were by far the commonest constituents of first-class turf. There existed the apparent anomaly of a despised grass species forming the bulk of the best fattening pastures in the country. Gradually it became realized that perennial ryegrass is an extremely variable plant, existing in all sorts of forms, from the very leafy and long-lived to the very stemmy and short-lived. The former plants came to be designated 'indigenous'; they were also called 'evergreen', because the tips of their leaves are not so liable to turn brown in winter as those belonging to the latter, or 'commercial' types.

This was the position during the early years of the present century. One valuable source of 'evergreen' perennial ryegrass was discovered on certain very old pastures in Kent; this seed gave rise to rather small plants of a very leafy nature, which had remarkably few flower stalks and a long length of life. This Kentish indigenous, evergreen ryegrass commanded respect and enhanced prices from those farmers who knew a good grass from an indifferent one, but the amount available was relatively very small.

Then came the 1914–18 war period, which, although it stimulated food production and the ploughing up of much grassland, did not encourage research into forage plants. After the war, however, occurred an event which has had far-reaching effects upon the improvement of grasses and grassland. This was the establishment of the Welsh Plant Breeding Station at Aberystwyth, with Sir George Stapledon as Director. The chief duty of this station was to improve the supply of grasses and leguminous plants, and naturally it took a great interest in perennial

ryegrass. It collected different types, or strains, of the species from all parts of the country and from abroad, grew them, compared them, criticized them, analysed them, and published reports on them. In this way it was able to establish and drive home the very considerable advantages possessed by certain indigenous strains over the majority of commercial strains in persistence, leafiness, freedom from winter scorch, and relative freedom from flowering stems. It was shown that strains from the Weald district of Kent, from certain districts of New Zealand, and from parts of Sweden, are much superior to ordinary unclassified commercial types.

Further, the Welsh Plant Breeding Station was able to develop new methods of cross-breeding grasses so as to combine the desirable qualities of two or more promising plants into one strain. This in itself was a notable piece of work, judged by purely scientific standards. Its commercial results were not realized by farmers until the 1939–45 war for it is a long and tedious business raising and marketing a new variety of plant. But in the Aberystwyth strain S.23 and in some strains from commercial houses we have long-lived perennial ryegrasses which in some districts have proved extremely valuable. Attention is also being paid to the breeding of special short-lived strains for special purposes.

Cocksfoot is another grass which has been the subject of much research during recent years. It is a grass which is commonly found in large tufts in orchards and rough pastures, having a very flat shoot and a flower-head shaped like the toes of a bird. The common name for this species used to be rough cocksfoot, for its foliage was harsh and rough to the touch, and the general coarseness of the plant made it much disliked by farmers, even for hay. But careful investigation showed that there is as much variation between plants of cocksfoot as between plants of perennial ryegrass, and it became possible to select plants with much smoother, more palatable leaves than others. It was possible to distinguish between early-maturing plants with numerous flowering stems, and late-flowering plants with a denser leafage at the base. The former are more suited to

mowing for hay, and the latter for grazing. Strains from Denmark and France are suited to hay purposes, strains from New Zealand (such as the Akaroa) and indigenous types from this country make excellent grazing plants. Hybrid cocksfoots such as S.26 and S.143, specially bred for persistence under pasture conditions, are now available. These improved plants have brought cocksfoot into favour on light soils unsuited to perennial ryegrass, largely because the habits of the plant are now better known, and it can be controlled by varying the management of the pastures.

The improvements to perennial ryegrass and cocksfoot just described have resulted in an increased productivity which the uninformed and unobservant might find it difficult to believe. The plant selector and breeder have also worked upon timothy and meadow fescue, but in the case of no other grass species have the improvements been so valuable as in ryegrass and cocksfoot.

Clovers have come in for a great deal of attention from all sorts of agricultural scientists during the past thirty years, particularly red clover and white clover. It is a difficult task to assess the value of our new knowledge concerning these two species, but the national agricultural wealth must be very much greater on its account. Clovers are leguminous plants belonging to the Family Leguminosae, all members of which have on their roots small swellings, called nodules. These nodules are not, as was at one time supposed, symptoms of disease. They are caused by certain bacteria which feed upon the clover whilst taking nitrogen from the air to build up their own microscopic bodies. Eventually the clover obtains some of this nitrogen from the bacteria by processes which have not yet been fully investigated. This removal of nitrogen from the air is a very remarkable thing, because plants other than leguminous plants have to get their nitrogen from the soil in a dissolved form, and nitrogen both as a fertilizer for crops and as a food for stock is an expensive element to buy.

Clovers, however, have roots, stems, and leaves which are very rich in nitrogen compared with those of other plants, and this extra nitrogen is obtained at no cost to the farmer. More-

over, as Virtanen has recently shown, the clover excretes combined nitrogen into the soil during its lifetime, and grasses growing in the immediate neighbourhood are stimulated by it. When clover is ploughed under during the breaking up of a temporary ley or permanent pasture, the roots decay and gradually release the stored nitrogen for subsequent crops.

Hence clovers are of extreme importance, and no intelligent farmer would dream of sowing down a field to 'grass' without including some clover. The most valuable clovers are Red Clover (*Trifolium pratense*) and White Clover (*Trifolium repens*), and we must now consider what recent research has done with these two species.

Red clover has been known to farmers in this country since about 1630, Sir Richard Weston being credited with its introduction. But although the plant has been grown here for three hundred years it is only during the last thirty years that the possibilities of the plant, and also its limitations, have been properly realized. As the result of long and tedious investigations conducted at the Welsh Plant Breeding Station and elsewhere, we can now group the numerous different types of red clover into three main classes—namely, wild, early-flowering, and late-flowering red clovers.

For the present the wild type may be disregarded, since it has been shown that it is a plant unlikely to influence farming to any great degree. The other two types are extremely important to rotation grassland, and the chief value of the investigations carried out upon them during the last twenty years lies in the discovery that some strains are much more productive and longer lived than others. Another service which these researches have performed is to kill the name 'cowgrass' formerly applied to these clovers. The name 'double-cut cowgrass' was used until recently to describe any red clover which could give two cuts of hay in a season, and the name 'single-cut cowgrass' to any red clover which could not give more than a single hay crop.

Now we know that strain in red clover is of the greatest importance, and that the beauty of a sample of red clover seed is not necessarily an index of its utility as a producer of herbage.

The best cropping strains frequently have seed which looks inferior to less valuable foreign strains. From repeated experiments the farmer may rest assured that red clover seed grown in this country is as a rule superior to imported seed, and that seed imported from temperate climates is likely to be superior to seed coming from warm countries. Strains of red clover from certain counties and districts of England and Wales are superior to other strains from other districts. Thus, the value of red clovers from the Eastern Counties, Dorset, Vale of Clwyd, Cornwall, and the Cotswolds has been amply demonstrated. Hence, under the provisions of the Seeds Act, 1920, vendors are compelled to state the country of origin of their red clovers, as a guide to farmers.

Recent work on red clovers has emphasized the extremely temporary nature of the early-flowering type, which usually lasts only one harvest year ; and also the fact that very few strains of the late-flowering type endure profitably for more than three seasons. The Montgomeryshire extra late-flowering red clover, Cornish Marl and certain Aberystwyth strains are the longest lived strains, but even these give very little yield after four seasons. Another discovery which is proving of value is that the late-flowering types give a heavier yield of hay than the early-flowering types, despite the bigger and broader leaves of the latter. Of course they do not give as much grazing after the hay has been removed, nor in the stubble during the first year of their existence.

If we agree with Stebler, the celebrated Swiss agriculturist, who said many years ago that the development of red clover as a farm crop has had an influence on rural and national life even greater than that of the potato, the importance of this recent work needs no further emphasis.

If increased knowledge of the red clover plant has put greater power into the hands of the man farming rotation grassland, even greater benefits have been derived for grassland as a whole from the study of wild white clover. This small, creeping plant, which is usually only noticed by the non-farming population when it is in full flower during the summer, must be regarded

as one of the most valuable of all farm plants. Certain it is that the value of farm land has been increased to an enormous degree by the extended growth of the species.

True wild white clover is a very different plant from the cultivated or Dutch white clover. It is smaller, longer lived, and grazes much better. It is rich in protein, the flesh-forming food, and comparatively rich in calcium and phosphorus, both of which are essential to the formation of bone and milk. It grows rapidly, and accumulates much fertility.

These facts were not discovered all at once. It was not until 1886 that the persistence of the true wild white clover, as opposed to the cultivated type, was first demonstrated by experimental plots. The source of supply was very old pastures in Kent, which were mown at intervals to obtain seeds of crested dogstail grass, and evergreen perennial ryegrass; wild white clover seed was then a sideline, a by-product. It is now the principal motive, and the grasses are relatively unimportant.

About 1906 it was discovered at an experimental station called Cockle Park, in Northumberland, that basic slag had a remarkably stimulating effect upon wild white clover growing in pasture and this in turn greatly increased the number of stock which the land would carry throughout the season. The land here was a cold, poor clay, but similar results were obtained some years later on a thin, light, chalky soil on the South Downs not far from Newhaven, in Sussex. It gradually became realized that the interaction of phosphatic manures, especially basic slag, and wild white clover, offers one of the best methods of improving grassland. On some soils the addition of potash fertilizers also is found necessary before the white clover can be stimulated. Later still it was realized that wild white clover develops very rapidly from seed if conditions are suitable. It sends its runners over the surface of the soil and soon binds the grasses together. The result is that a good turf is formed very much earlier than would be the case if wild white clover were not included in the seeds mixture.

Some idea of the increasing respect for this plant may be gathered from the fact that whilst in 1907 wild white clover seed

could be obtained at 1s. 6d. a pound, by 1916 it cost 18s. 6d. a pound. As a consequence of the publication of a report showing how useful wild white clover had been in restoring fertility to a farm on the Downs in Sussex, the price rose to 22s. in 1918, and reached a maximum of 35s. a pound in 1920. Larger supplies are available now than there were thirty years ago, and the price per pound in 1950 was about 12s.: a short time previously it has been as low as 10s.

Despite the popularity of wild white clover as a grazing plant, some agricultural scientists were far from satisfied with its productivity. It is a small plant and its yield of fodder is not great. Certain forms of white clover are very much bigger than the wild variety, such as the Dutch white and Ladino white clovers. But these two types are short lived and not very hardy. The search for a long lived, larger white clover resulted in the almost simultaneous development of two strains which have become enormously popular during the last ten years. They are the New Zealand Mother white clover, and S.100 white clover, which is a hybrid form developed at the Welsh Plant Breeding Station. These two clovers, which are very similar, develop more rapidly than wild white clover and are considerably bigger in both leaf and stem. They may not be so long lived as the wild type, though they may last for seven or more years, but they have enormously simplified the business of ley formation on many soil types in different parts of the country, especially the northern and western portions. One can almost say that the inclusion of 2 to 3 lb. per acre of either clover is a guarantee against failure in pasture establishment.

From the foregoing it is clear that the present-day farmer has at his disposal a number of pasture plants much better than those available to his father or grandfather. But agricultural science has not only provided better raw material in the shape of grasses and clovers; it has demonstrated by experiments in all parts of the country how these plants may be controlled and made to yield the maximum amount of fodder.

To take seed mixtures first. Little need be said about the ordinary ley destined to yield for twelve months only. No revolu-

tionary changes have been made in the one-year seeds mixture as the result of recent scientific investigation. Perennial ryegrass, Italian ryegrass, red clover, and alsike clover are still the most important plants used for one-year leys over large areas, though the use of timothy for these short leys is on the increase. For a single heavy hay crop it has been shown that perennial ryegrass combined with a late-flowering red clover will give heavier yields than Italian ryegrass and an early-flowering red clover. But because very many farmers wish to graze the ley or make use of the aftermath in various ways, the two latter species are often included.

In fact, so far as weight of hay from the one-year ley is concerned, we are probably little better off than were farmers two hundred years ago. Red clover sown alone will, in a good year, give better results than a mixture of clover and ryegrass. But since every year is not a good year for red clover, it is generally considered more prudent to include some ryegrass. Alsike clover can be used as well as red clover. Recommendations for a one-year seeds ley are very numerous; usually about 14 lb. of ryegrass and from 4 to 6 lb. of red clover seed per acre are considered sufficient. If alsike clover is favoured, from 1 to 2 lb. per acre of this much smaller seed are included. As already stated, the use of timothy for short leys is spreading, the timothy replacing the ryegrass.

In the case of seeds mixtures for long leys and permanent pasture, however, very considerable changes have taken place during the last two decades—the general tendency being towards simplification. The older seeds mixtures were complex ones, and were made up of the seeds of a dozen or more species of pasture plants. There might be eight or ten grass species, and four or more species of leguminous plants. There might be 1 lb. per acre or even less of the seed of some of the species. The ideas behind the complex seeds mixture were chiefly these. It was thought that by the inclusion of a large number of species the 'take' or establishment of the pasture would be more certain than with a smaller number of species, since some at least of the different plants would find conditions to their liking. It was

thought, too, that grasses vary considerably in their nutritive value, and that variety was a good thing. Above all, it was thought that by including in the same mixture plants which start growing early in spring and plants which develop late in the season, the pasture would be made productive right throughout the year.

Recent investigations have shown that some of these premises are unsound. Analyses show that the commonly used grasses do not differ very much in their nutritive value, but that each species has very different nutritive values at different stages of growth. The younger the grass the more nutritious it is. Management is as important as variety or species in obtaining young succulent fodder throughout the season. Also, it has been demonstrated that certain species of grass, sown in small amounts, are unable to establish themselves in competition with other, quicker-growing and more vigorous, species. It has been shown, too, that of the species sown in a complex seeds mixture for permanent grassland, only about six or eight at the most are likely to survive in any appreciable amount by the time the turf is five or six years old.

As an example of a simple seeds mixture for general purposes over a long period of years, the Cockle Park mixture sponsored by Gilchrist is set out below:

Perennial ryegrass, 16 lb. per acre; cocksfoot (chiefly New Zealand), 10 lb.; timothy (preferably Scotch), 4 lb.; late-flowering red clover, 4 lb.; trefoil, 1 lb.; wild white clover, 1 to 4 lb.

Only six species are included in this mixture, but with the exception of trefoil the rate of seeding is heavy.

Even simpler mixtures have given good results in various parts of the country, for it has been found that a combination of 12 to 16 lb. perennial ryegrass, or cocksfoot or timothy, and 2 to 4 lb. white clover per acre will often give rise to a very good turf without any additional species whatsoever.

Ultra simple mixtures have become popular in some counties, where the constituents are merely 6 to 8 lb. of one of the extra leafy strains of cocksfoot, timothy or perennial ryegrass and 2 to 3 lb. of S.100 or New Zealand white clover.

To older farmers brought up to regard 30 lb. of seed per acre as the minimum requirement for establishing grassland it is almost incredible that good results can be obtained from such low seedings as these, but the fact is indisputable. Success with these light seedings is due chiefly to two things. First, the great speed at which the 'large' white clover will cover bare ground brought into suitable condition for sowing (and, of course, the large number of clover seeds sown: there are approximately 800,000 seeds of white clover per pound). Second, the vigour of the leafy types of grass when freed from the competition of other species. For example, perennial ryegrass is an 'aggressive' species, and will not allow any other grass sown with it to develop to its maximum.

It must not be inferred from what has been said about simple seeds mixtures that finality in sward formation has been reached. Difficulties with stock have arisen in some districts in the utilization of leys originating from very simple seeds mixtures, though in others more satisfactory results have been achieved. In some cases livestock have shown their disapproval of the herbage by refusing to graze, and by searching the hedgerows or even by breaking out of the fields. Accusation of various signs of ill health in stock, including unthriftness and diminished fertility, have been made against simple leys: at the moment these statements have been neither proved nor disproved. Obviously much more research will have to be carried out on such points.

It is known, of course, that certain 'herbs' such as yarrow, plantain, chicory and burnet are much richer in minerals than are the commonly cultivated grasses and clovers. The use of such herbs in seeds mixtures was advocated as long ago as 1887 by R. H. Elliot in his Clifton Park system of farming, though he recommended them mainly because they are deep-rooting plants which can tap the plant food in the lower layers of the soil. Nowadays the use of herbs is recommended chiefly on account of their richness in calcium, magnesium, etc., and because they supply variety in the diet. The best way of introducing these herbs into a ley is still a matter of controversy: some farmers keep the herbs more or less separate in a 'herb-strip' so that they

will not interfere with haymaking, while others prefer to mix them up with the grasses and clovers.

By the use of properly compounded simple seeds mixtures, a good close turf can be established very much more rapidly and certainly than at any period of British farming. This is a fact that is bound to have profound results when its implications have become fully realized by farmers, and, it must be added, by land owners as well. It was commonly held years ago that every permanent pasture goes through three well-defined stages of existence. First of all there is a period of luxuriance for two or three years whilst short-lived grasses and clovers predominate. Then comes a period of poverty lasting from three to four, or up to ten years, during which the permanent grasses are slowly developing, followed by a third stage characterized by a 'rich velvety covering of perennial ryegrass and white clover characteristic of our best pastures'. It was thought that a good turf could not be established in less than twenty years.

This view is now out of date. It has been conclusively shown by innumerable experiments and demonstrations in all parts of the country that on all but the most unsuitable soils it is possible to get a good turf in two or three seasons, or even less—provided a suitable seeds mixture, including not less than 1 lb. of wild white clover per acre, be sown, the soil be properly manured, and the grass be managed in the right manner.

To get these quick results the seeds should not be sown in a cereal crop. For a one-year ley the farmer is compelled to sow the seeds in the spring-sown cereal—oats or barley usually—in order to save time. But in the case of a long ley there is no such necessity. What counts most is the turf itself. The value of a 'nurse' crop has in the past been very much overrated. The cereal may protect the young grass and clover seeds from a hot sun, but in many ways it is extremely detrimental to them, cutting out light and air and competing with their roots. It is also very difficult to get the soil on which the cereal is growing into that fine state which grass seeds need for really good germination and establishment.

The modern alternative method, called direct seeding, is to

put the grass seeds into bare soil either without any nurse crop at all, or with a few pounds of rape seed or Italian ryegrass to give some protection in the very early stages. About eight weeks after sowing the seedlings can be lightly grazed. By doing this the livestock not only consolidate the soil, but also begin the process of distributing 'stock nitrogen' in their urine, which has been found so beneficial to a turf. In an incredibly short time—a few months only in some cases—the wild white clover knits together the grasses into a turf which need never show signs of poverty under proper management.

Another thing which has been re-emphasized by recent experiments is this, that livestock, properly managed, are as essential to the maintenance of good grassland as are fertilizers. The good grazier has always realized this, but the point was driven home by a series of experiments carried out by Martin Jones at Jealotts Hill, in Berkshire. It was found possible to change the botanical nature of a turf by managing the grazing in different ways. By heavy grazing in spring wild white clover could be greatly encouraged, and conversely, by allowing the grasses to grow long, the clover could be much reduced. By grazing just when any particular grass came into vigorous growth this species could, in the space of a year or two, be almost exterminated. A turf composed of perennial ryegrass, cocksfoot, rough-stalked meadow grass, and wild white clover could at will be so altered by management as to become chiefly ryegrass, chiefly cocksfoot, or chiefly wild white clover.

During the 1939–45 war there was a very remarkable change in the attitude of farmers towards permanent grass. Six million acres of old turf were ploughed up mainly for the production of arable crops, and of this total a great many acres have now been seeded back to longer or shorter leys. These leys, when properly laid down and correctly managed, have proved themselves to be more productive than the old turf which preceded them. Farmers have been encouraged to look upon their old pastures with a fresh eye, and they have discovered many of them to be unremunerative compared with younger turf. The compelling need of increased food production, and the overriding by the

Government of restrictive clauses in farm agreements were the reasons for the breaking up of this enormous acreage of old turf land. There have been two principal results. First, a great quantity of much-needed grain and potatoes has been grown, and second, there is every prospect that much of this land, when it is seeded back to grass, will be more productive than when it was in permanent pasture.

Since 1938 scientists have devoted much time to the grasslands of England and Wales. In that year a grassland survey of England was begun by the Aberystwyth workers at the request of the Ministry of Agriculture, on lines similar to those adopted for the grassland survey of Wales. The conclusion of the surveyors made melancholy reading, for they were unanimous concerning the average poorness of our permanent grass. Only a very small percentage could be looked upon as first class, and there was a very high proportion of poor quality pasture, characterized by the predominance either of bent-grass (*Agrostis*) or of tor-grass (*Brachypodium*), both very inferior agricultural grasses. In addition, many thousands of acres of permanent grass had had their value still further reduced by bracken, thorns, brambles and ant-hills. Over vast areas the soils under these turfs was both lime-deficient and starved of phosphates and sometimes of potash.

The problem of producing arable crops from these poor pastures was very much a matter of supplying the lime and phosphates after the engineering problem of breaking up the sod had been solved. Some of the poor turf was not suitable for arable crops because of its situation and slope, and to make it more productive a technique of direct reseeding was adopted. The term 'direct reseeding' should really be restricted to those cases where old turf is ploughed, and after suitable cultivating and manuring, is straight away sown with grass and clover seeds. The term is, however, used to describe any case where grass and clover seeds are sown without a cereal nurse crop.

This technique now seems very simple, but it had to be worked out slowly and painstakingly, bearing in mind all the time the practical difficulties of the farmer. Briefly, the technique of direct

reseeding demands first of all good ploughing to bury and kill all the old turf; disc harrowing to produce a suitable surface tilth; generous application of lime, phosphates and nitrogen: thorough consolidation of the soil: use of a suitable seeds mixture; deep burying of the seeds in a dry district; properly controlled grazing during the first season, and continued intelligent management thereafter.

All these operations are based upon scientific observation. The need of lime for plant growth has already been mentioned (page 27), whilst of recent years, the influence of phosphates upon root growth of all plants, and upon the establishment of leguminous seedlings, has been studied very intensively. So, also, has the need of grass and clover seedlings for a properly consolidated seed bed, without which their roots are unable to develop, so that the young plants perish. Very striking facts about the depth at which herbage seeds can be sown have come to light in recent years. It has been shown that even on stiff clay soils grass seedlings can in normal seasons develop quite happily in a properly prepared tilth from seeds sown at least one inch deep, while on light land successful establishments have sometimes been made from grass and clover seeds planted over two inches deep. This is important information, and in districts where the rainfall in spring is very light it is now common practice in direct seedings to drill the seeds about an inch deep with an ordinary corn drill (care must be taken, however, with timothy seed and white clover). This places the seed in moist soil and prevents the droughting out of the seedling which commonly occurs when seeds are broadcast and covered with toothed harrows. When a corn drill is used, with coulters from six to seven inches apart, the drilling is often done in two directions so as to get a better distribution of the seed. Flax drills, and special grass seed drills having coulters only three or four inches apart, are now available, and when these are used a single drilling is sufficient. The intervening ground soon becomes covered by the white clover used in the mixtures. An alternative method of placing seeds well below the surface is to broadcast and harrow in with disc harrows set quite, or almost, straight. Early

grazing of the young seedlings is needed, partly to consolidate the soil around their roots by the treading of the animals, and partly to encourage tillering of the plants themselves. This grazing is an essential part of the technique: if by any chance stock are not available, the action of stock must be imitated by rolling and mowing whilst the seedlings are still small—an early silage cut may be taken. To allow the plants to run up unchecked to the hay stage during the first few months is fatal.

Since 1940 there has been a great extension of the area in this country devoted to the growing of herbage plants for seed. A certain amount of red and white clover has been grown here for many years, but previous to 1938 the acreage devoted to grass seed growing was very small indeed, and only a tiny fraction of our needs was home supplied. With the cutting off of foreign supplies, and with increasing recognition of the virtues of certain home-bred pedigree grasses and clovers, herbage seed production received a great stimulus. The problem here which the scientist and the farmer have to solve is a complex one. The scientist has to breed plants superior to those obtainable anywhere else in the world, and then he and the farmer have to devise a technique of seed growing that will produce the seed of this desirable plant at a price which will compete with imported seed of a comparable type. The strains of such superior plants already exist, and much experimental work has been carried out on the latter point. It is known, for example, that more seed per acre is produced from grasses grown in widely spaced rows than from broadcast plants. But this does not necessarily mean that seed from drilled crops can be produced as cheaply per pound as that from broadcast seed. All sorts of other things have to be taken into consideration: grasses in rows need much attention to keep down weeds, and they cannot be grazed in the manner possible with seeds broadcast with a clover. Some grasses, like perennial ryegrass and timothy, give quite good yields the first harvest year if they are sown the previous season under a cereal nurse crop: cocksfoot, however, yields very poorly the first season with such treatment, and prefers to be sown on bare ground. There is consequently no nurse crop to be harvested the first year to off-

set the cost of production of the cocksfoot seed. An alternative is to plant after early potatoes. The best method of herbage seed production under different farming conditions therefore demands much more investigation if the industry is to supply good seeds to British farmers at a reasonable price and also to survive foreign competition.

Great increases in our knowledge of the chemical composition of grassland plants have been made during the past quarter of a century, such as those concerning the superior richness of the leaf compared with the stem of grasses: the richness in minerals of white clover and herbs like plantain and chicory: the effects of frost and so on. And of course the very high protein content of young grass only a few inches tall, a discovery made by H. E. Woodman about 1927 which has revolutionized thought concerning home-grown protein and has given rise to the great industry of grass drying described in Chapter Ten.

COLLATERAL READING

An elementary guide to the identification of grasses and clovers can be found in *Common British Grasses and Legumes*, by J. O. Thomas and L. J. Davies (Longmans, Green, 1949): further descriptions are given by D. H. Robinson in *Good Grassland* (E.U.P., 1947) and *Leguminous Forage Plants* (Ed. Arnold, 1949). *British Grasses and their Employment in Agriculture*, by S. F. Armstrong (C.U.P., 1943) is an invaluable guide to farm grasses.

Ley Farming, by Sir R. G. Stapledon and W. Davies (Faber and Faber, 1948) is packed with information about grassland, and should be read in conjunction with Sir R. G. Stapledon's *The Plough-up Policy and Ley Farming* (Faber and Faber, 1939), and his earlier book *The Land: now and tomorrow* (Faber and Faber, 1936). For the technique of grassland management see H. I. Moore's *Grassland Husbandry* (Allen and Unwin, 1943) and *The Science and Practice of Grassland Farming* (Nelson, 1949), and W. R. Peel's *Grassland Management for the Practical Farmer* (Macmillan, 1938). Consult also J. F. H. Thomas's *The Grazing Animal* (Faber and Faber, 1949).

Chapter Five

FARM PESTS

Pests on general and specialized farms—cost of pest damage—definition of insect—early investigations—warble fly—life history—method of control—use of Derris—legislative control—example of Denmark—Warble Fly Order—sheep scab—sheep dipping—dual purpose dips—lice and fleas—sheep maggot fly—pests of crops—need for crop rotation—potato root eelworm—its dispersal—possible control measures—wireworms—experiences during war-time ploughing of old grass—control by cultivations and soil insecticides—leather jackets and cut worms—slugs—wheat bulb fly—black fly on beans and sugar beet—forecasting severity of attack by black fly—carrot fly—gassing of field crops—new insecticides—DDT—benzene hexachloride—control of turnip flea beetle—organo-phosphorus insecticides—HETP—systemic insecticides

The big-game hunter is much more likely to suffer injury or death from insects than from the big mammals which are his quarry. Civilization is indeed a continuous fight against all sorts of insect enemies, and the farmer, no less than the tropical engineer or medical officer of health, has to spend a great deal of his time considering how to outwit and destroy his tiny six-legged opponents.

In this chapter the case of the general farmer only will be considered. The fruit farmer and the horticulturist have to contend with many more insects and allied pests than the mixed farmer, largely because their industries are so intensive and be-

cause each individual plant has a greater value than is the case on a general farm. Only a specialist can hope to have a knowledge of all the very numerous insects likely to attack fruit trees and garden and glasshouse crops. Large sums of money have to be spent every year on chemical spray fluids and fumigants to combat these pests, but on the general farm the position is perhaps not quite so serious. Certainly the general farmer cannot afford to spend as much on these substances as the horticulturist.

It is very difficult to obtain a reliable estimate of the losses caused by insect damage to farm crops and livestock. The partial or complete failure of a crop may be due partly to insect attack, partly to fungus diseases, partly to weather and cultural conditions; to assess the damage brought about by each of these is an impossible task. For these and other reasons it is more or less pure guesswork to state a figure for the losses caused to agriculture by insect pests. The figure of £6,000,000 annually was mentioned as the cost of insect damage to crops alone in this country, just before the second world war, taking no account of damage to livestock, timber, and stored products.

Most of the small creatures included in the term 'pest' as used here are insects. In the correct sense of the term an insect is a creature belonging to the Order Hexapoda or Insecta, having three pairs of legs in the adult state, a body divided into three parts, and usually having wings. This definition would exclude animals such as spiders, mites, ticks, millipedes, slugs, snails, and eelworms; but all these creatures are the concern of the agricultural entomologist, and for our purpose can be classed as insects.

In what ways has science assisted the farmer to overcome his insect enemies? Actually it is just over 100 years since the careful study of agricultural insects really began. About 1840 John Curtis began writing articles on insect pests in the Journal of the Royal Agricultural Society, and in 1859 he published a book on *Farm Insects* which is still regarded as a standard work. Then from 1881 onwards, Miss Ormerod, one of the most indomitable women of her time, published at her own expense a Report on Injurious Insects every year for twenty-four years. These manuals, or pamphlets, gave the latest information about farm

pests, and greatly stimulated investigations into their behaviour and control. Since the beginning of the present century the Government have assisted research into entomological problems of all descriptions, and dozens of workers in this country alone are investigating different aspects.

As a result, the farmer of to-day is better able to deal with most of his insect enemies than were his father and grandfather. The farmer benefits from two main developments in entomological work: first, the careful study of the life history of the pests and second, the utilization of new methods of cropping, cultivation and chemical substances in destroying the insect during its most vulnerable stage of development.

To illustrate this contention we cannot take a better example than the warble fly. This is a large fly which could quite easily be mistaken for a bee. The larvae, or maggots, of this insect spend a large part of their life along the backs of cows and bullocks immediately beneath the skin. In spring, the presence of the grubs is made known by the swellings which arise over them. To obtain air the maggot, which is commonly called the 'warble', pierces a hole right through the skin; when the cow or bullock is killed and the skin dressed, these breathing holes appear as perforations in the hide, with the result that the value of the leather is very much reduced. Warbled hides may fetch from one penny to threepence per pound less than first quality hides. Until recently the annual loss to the leather trade on account of warble fly damage in Great Britain amounted to about half a million pounds. The direct loss to farmers and graziers cannot be estimated, but it is well known that beasts infested with warbles are more restless and do not thrive so well as beasts which are warble-free, on account of the irritation set up by the parasites.

Warbles have been a pest from time immemorial, but only recently has it been possible to control them. There are several reasons for this. In the first place, the true life history of the parasite has only recently been worked out. Early investigators, including a number of well-known scientists, made a false deduction right from the start, which led to considerable confusion and to recommendations which would have resulted in a great

waste of time and energy on the part of farmers had they been extensively carried out. These investigators noticed the swelling warbles along either side of the spine of cattle, and immediately assumed that the warble fly laid her eggs on the backs of livestock. 'If we can smear the backs of cattle with substances unpleasant to the female fly', they said, 'we shall prevent egg-laying and solve the problem.' So during the months when the fly was known to be on the wing, farmers were encouraged to cover the backs of their animals with all sorts of evil-smelling oils and ointments to act as deterrents. All these dressings were quite useless, but it was difficult to convince people of this until Carpenter's experiments during the three years 1904–7, and even now it is not easy to get the older farmers to appreciate this fact. Carpenter dressed sixty-seven calves and kept with them twenty-four untreated calves. The average numbers of warbles per animal were: treated, 10, untreated 12. He treated the backs of twenty-eight yearlings, and kept eleven untreated yearlings with them. The treated animals had an average of 24·5 warbles each, the untreated animals 27·6 warbles. This was sufficient proof that dressing the backs of cattle has no influence on warble fly attack.

Gradually new and accurate information about the habits of the warble fly was gathered together, until about 1916 an amazing life history became revealed. This is the behaviour of the warble fly, or rather flies, for there are two different species now known. The female is on the wing during the summer months, and sticks her eggs on to the hairs of cattle, either singly or in rows according to the species of fly. But the insect never lays eggs on the *backs* of cattle. Usually it is the lower parts of the legs which attract the flies, though sometimes eggs are stuck to hairs on the underside of the belly. It was on this point that the earlier workers went wrong. Obviously, if the fly has no interest in the backs of cattle it is waste of time trying to keep her off this region.

The eggs hatch in four or five days, and tiny maggots emerge, which at once crawl down the hair to which the eggs are attached, and burrow into the skin, and disappear. Where have they gone? We do not know exactly how they get there, but several weeks

later these maggots are to be found in the tissues of slaughtered cattle in the region of the gullet, that is, the tube leading from mouth to stomach. Possibly they make the long internal journey from the legs to the front of the body by getting into a blood vessel and being carried along in the blood. The maggots remain near the gullet for some weeks, even months, until they are about half an inch long, whereupon they make their way through the flesh of the beast, up along the ribs, to the back. They bore breathing holes through the skin and feed upon the inflamed flesh of the beast, until in the spring they become full grown. They then wriggle out of the hide, fall to the ground, and pupate, that is, go into a resting stage. Six weeks later the fly emerges from the pupa.

This is an extraordinary life history, and it took a long time to work it out. The passage of the maggot from leg to gullet was so unexpected that special experiments were necessary to prove that the eggs were not licked off the hairs and transferred to the gullet via the mouth. The life history once established, however, it became obvious that the only way of fighting the pest is to kill the warbles before they escape from the backs of the cattle. Dressing the legs and bellies of animals with deterrents is not possible on the farm, since no effective deterrent is known and the practical difficulties are too great.

The warbles can be squeezed out in spring fairly easily, and such prematurely removed maggots do not form pupae. But to remove thirty or more warbles in this way from a single animal takes a lot of time, and in a large herd tremendous labour is involved. Also, it is necessary to examine animals more than once, because the maggots may be making their way to the back over a period of several weeks, and late arrivals might escape. For similar reasons, the injection of lethal substances into each warble with a hypodermic syringe is not a practical proposition on the farm, however efficient it may be under experimental conditions. Some cheap substance is required which can be easily brushed over the backs of cattle, killing the maggots but not harming the cattle.

All sorts of oils, sheep dips, tars, and so on were tried, but

only tobacco-and-lime was found at all satisfactory, and there were objections to this. Round about 1920 chemists engaged upon entomological problems began to take a great interest in tuba-root, a tropical arrow poison, the main source of which is the root of a tropical plant called *Derris elliptica*, or Derris, which was found to be very deadly to insects. Mention has already been made of the very considerable lag between the discovery of a new principle and its application to farming, and here is an instance of a chemical discovery lying fallow for seventy years. It was suggested by Oxley as long ago as 1848 that tuba-root might be employed against insects; natives in Malay had long used tuba-root as a fish poison, and the Chinese had also employed it as an insecticide. But not until the second decade of the present century did the white races pay much attention to this, as we now know, remarkable plant.

Investigations in this and other countries soon showed that derris possesses very valuable properties. It is relatively harmless to mammals, including man, but is very deadly to fish and insects. It kills insects both by contact and when taken into the stomach. The poisonous principle is called rotenone, and at first there was some difficulty in standardizing the rotenone content, with the result that preparations of derris gave differing results at different times when used as insecticides. Rotenone is now obtained from plants of the genus Lonchocarpus as well as from Derris. This substance attracted the attention of those working on the warble fly problem, and experiments carried out in various parts of the country, notably in Worcestershire and Scotland, between 1924 and 1931, showed that derris powder combined with soft soap can kill warbles very cheaply, effectively and without harming cattle, if properly applied to their backs at the proper time.

But a fresh problem now arose. A farmer might have the knowledge and materials necessary for the destruction of warbles in his cattle and dairy cows, but could he be induced to carry out the work if his neighbour neglected to do likewise? Warble flies do not travel great distances, but obviously flies hatched out on an infected farm might easily lay their eggs on cattle belonging

to a neighbouring farmer who had spent a lot of time and trouble in clearing his own farm. It was realized that the warble fly would have to be regarded as a national problem.

Denmark anticipated us in this matter by several years. In 1922 it was estimated that 20·5 per cent of the hides in that country were perforated with holes made by warbles. In 1923 the Danish Legislature introduced regulations compelling farmers to destroy warbles in their herds, with the result that by 1924 the percentage of warbled hides dropped to 4·5 per cent.

In 1936 the Ministry of Agriculture and Fisheries issued the Warble Fly (Dressing of Cattle) Order, which requires all visibly infected cattle to be treated with a preparation compounded of 1½ oz. of derris resins (or ½ oz. of rotenone) and 4 oz. of soap. The treatment must begin between 15th March and 22nd March, or as soon after these dates as the maggots appear under the skin on the backs of cattle, and must be repeated at intervals of not less than twenty-seven days nor more than thirty-two days as long as the maggots continue to appear. Alternatively, mechanical means (such as squeezing) may be employed to remove and effectively destroy all ripe maggots at such intervals, not exceeding ten days, as may be necessary to prevent the escape of live maggots. Treatment by either of these two methods is not required after 30th June in any year. During the 1939–45 war this Order was suspended owing the impossibility of obtaining rotenone, but it has since come into force again.

The warble fly pest has been treated at this length because it illustrates very well how science is being brought to the aid of farming. First, there is the realization of the damage and failure of rule-of-thumb methods to cope with the pest. Second, there is the slow and painstaking study of the parasite and its method of living, a study in which many workers are engaged, each adding a few items of information which are slowly built up into a complete picture. Next come the experiments to determine the best way of breaking the life cycle, usually involving co-operation with the experimental chemist; successful experimental methods have then to be simplified and recommended in such a way that they may be freely used under farming conditions—for these

may differ very considerably from experimental conditions. Finally, in some cases, regulations have to be drawn up on a national scale to compel universal adoption of control measures, so that farmers who take the trouble to combat the pests do not have their work thrown away through the carelessness and selfishness of their neighbours.

A further instance of legislative control of an 'insect' pest of farm stock is provided in the regulations dealing with sheep scab. Scab, or scabies, or mange is caused by various microscopic mites which live on, or just beneath, the skin of sheep and other farm animals. The irritation set up by the parasites causes a crust, or scab, to form over the mite, and allows the affected animal no rest. The wool drops out and the sheep may become so emaciated that it dies. Infection is spread by contact between healthy and contaminated animals, or through rubbing against posts and fences used by scabby sheep. When it was shown by scientific investigators that scab could be controlled by dipping infected sheep in solutions of certain chemicals, the Government felt compelled, in the interests of farmers themselves, to make sheep-dipping compulsory throughout the country. At the same time, since conditions under which sheep are kept vary so much in different counties, the working of the regulations is left in the hands of local authorities.

Sheep dips contain various substances such as nicotine, carbolic acid, sulphur, or arsenic. A great deal of research has been conducted, both by commercial firms and official research workers, into the questions of dips, but so far nothing has been discovered which will kill the eggs of the scab mite without harming the sheep. That is why local authorities, in the case of an outbreak of sheep scab, compel the owner to dip his sheep twice. The first dipping kills the actual mites; investigation has shown that unhatched eggs are not destroyed, but develop about ten days later. The second dipping, which must take place not earlier than the eighth, and not later than the fourteenth day following the first dipping, kills the mites emerging from these eggs before the mites themselves are old enough to lay more eggs.

Very recently there have been introduced dual-purpose dips

containing both benzene hexachloride and DDT (see p. 107): these have given promising results against both sheep scab mite and the sheep maggot fly. These two chemicals retain their toxicity for long periods, so that larvae hatching out from eggs (which are not destroyed by the insecticides) over a period of several days are killed by coming in contact with the residue of the chemical.

Although from a scientific point of view the control of sheep scab offers no insuperable difficulties, the disease is by no means stamped out in hilly districts where sheep roam in large flocks over wide areas. Natural difficulties and the human element have so far kept the disease alive in these areas.

In a minor way, new discoveries are assisting in the control of other insect parasites of farm stock. Poultry, for example, are frequently plagued with lice and fleas which, on account of the irritation they cause, may bring about considerable losses. The discovery of the insecticidal properties of derris powder and sodium fluoride, and later, of DDT made it possible to destroy the parasites quite effectually, and these substances have supplanted the old type of pyrethrum powder to a considerable extent. Modern pyrethrum powder, though, is quite an effective insecticide. The use of these powders, however, necessitates handling each fowl individually, and takes considerable time. Quite recently, preparations containing nicotine (the alkaloid present in tobacco) in a volatile form have been employed against bird lice and fleas. The liquid is painted over the perches on which the birds roost; during the night the warmth of the birds causes a vapour to arise which penetrates their feathers, destroying the parasites without injury to the fowls.

It must be confessed, however, that the sheep maggot-fly has so far not been overcome by modern science. This insect, or rather insects, for there is more than one species, lays its eggs in the wool of sheep; and the maggots which hatch out feed upon the flesh of the unfortunate sheep, causing much pain, and even death, for in hill districts 'struck' animals may wander off and perish before they can be discovered and treated.

The new insecticides benzene hexachloride and DDT are

assisting the shepherd to some extent because they remain active for a longer time than most of the substances hitherto used for the treatment of 'struck' sheep. It is possible to use these materials as a spray and so give mass preventive treatment to a flock in place of individual attention.

It is, of course, possible to cure 'struck' sheep by individual attention and local treatments with sulphur and other compounds. What is urgently wanted, however, is information about the quality in sheep's wool which attracts flies, because this may lead to the successful use of deterrents, and up to the present no such efficient substances have been discovered.

Turning now to a consideration of insect and allied pests attacking farm crops, modern science tends to emphasize more and more strongly the necessity for sensible crop rotations and good farming methods in the control of these parasites. Modern farming, particularly the more intensive forms, provides pests and fungus diseases with almost unlimited opportunities for development. Food is often the limiting factor in the multiplication of insects, and the crowding together of individual plants into a crop offers every inducement for a pest to begin and continue its destructive work. If a crop like potatoes is grown year after year upon the same land, an uninterrupted supply of food becomes available for any enemy which is partial to this plant. In some fertile parts of the country potatoes have sometimes been grown several years in succession upon the same land. Usually the yield diminishes; in farming phraseology the land becomes 'potato-sick'. The cause is partly the increase in numbers of an eelworm, the potato-root eelworm, which lives on the roots of the potato.

The potato-root eelworm is a comparatively new pest in British agriculture, for it was not reported before 1913, when it was discovered in Scotland. Four years later it was found in Yorkshire, and since then it has spread into Lincolnshire and the adjoining counties, into Lancashire, Bedfordshire and many other potato growing areas. War-time demands upon potato growers caused the potato crop to be planted upon the same land more frequently than would normally be considered safe,

with the result that potato-root eelworm is now one of the most serious disorders the industry has to face. The disease can be recognized by the presence of small whitish or yellowish cysts on the rootlets of the plant. These cysts, which are about the size of a pin's head, are developed from the fertilized female eelworm. Each cyst consists of a tough envelope containing up to 600 eggs, and these cysts and eggs may be widely scattered in an infected soil. The eggs remain dormant until a potato crop is planted; it appears that the roots of a potato excrete a substance which stimulates the egg into hatching, whereupon a minute larval eelworm escapes into the soil and enters and feeds upon the roots of the plant. The male eelworms eventually leave the root, but the female remains permanently attached and forms the cyst.

The practical control of this pest has so far eluded science. Wide rotations are obviously desirable but not altogether easy to bring about in practice. It is, too, an unfortunate fact that the eelworm does not decrease very rapidly in the absence of potatoes, but does increase extremely fast when potatoes are present. Even a few 'ground-keeping' potatoes in a field may spoil the good effects of a long rotation. While it is easy to destroy the cysts and eggs on a laboratory scale with various disinfectants and fumigants, on a field scale this has so far been found impracticable, partly because of the resistant nature of the cyst wall and egg wall, but also because of the difficulty of properly fumigating any depth of soil. The present line of attack is this: it is known that the roots of the potato and of certain grasses excrete a substance which encourages the eggs to germinate: also that the free-living larvae are less resistant to chemical disinfectants than the eggs. By analysis of the substance—the so-called 'eclepic acid'—it is hoped that a material may be found and produced sufficiently cheaply to apply to infested ground in the absence of potatoes to make the larvae hatch. The larvae, it is hoped, can then be destroyed by chemical means or starved out by a long rotation.

Since 1938 entomologists have discovered quite a lot about wireworms. The wireworm, of course, is the cylindrical, yellow-

ish larva of the click beetle: the female beetle lays its eggs in grassy places, and the larva feeds underground for a number of years before pupating and developing into the adult beetle. When old grassland is ploughed up and a crop is planted, damage by wireworms can be very severe. These creatures jumped into prominence as soon as the policy of ploughing out old grassland came into operation and in 1940 in particular they caused a great deal of destruction amongst the badly needed cereal crops. There was then a widely held view that the more neglected the grassland the higher would be the wireworm population. But this was found to be inaccurate, and crops planted upon good turf ploughed-in suffered as badly from the pest as crops grown on most inferior turf. The Ministry of Agriculture sponsored an elaborate investigation into the distribution and behaviour of wireworms as soon as the war started, and this survey has brought to light a number of interesting facts about the insect. A method of estimating the number of wireworms in the soil was devised: it is a simple method, which involves the taking of a certain minimum number of soil samples by means of a borer 4½ in. in diameter operated to a depth of six inches. If the estimated number of wireworms is less than 300,000 per acre it is now assumed, with a fair degree of accuracy, that the field can be safely planted with any crop, provided of course, that soil conditions, fertility and so forth are satisfactory. If, however, the sampling reveals a population of one million wireworms or over, then the farmer must be on his guard, because the field is risky for most crops. Peas, beans, linseed, or cereals mixed with vetches or peas to be cut green, are probably the safest crops to grow in such cases.

There is no doubt that cultivations properly carried out can do much to reduce wireworm damage. In many districts a bare fallow, beginning in May and conducted with plenty of stirrings of the soil, appears to reduce to negligible proportions the chance of wireworm damage to a following cereal crop. Good cultivations and thorough consolidation, and where necessary nitrogenous top dressings, also minimize damage. The new insecticide, benzene hexachloride, described later, has been found

very useful in reducing damage through attacks by wireworm: it is certainly more effective than any of the materials previously used as a repellant in the soil such as naphthalene. It can be broadcast or be distributed by combine drill. The latest development is the use of BHC as a seed dressing (see p. 107).

There are two other kinds of insects whose larvae are soil inhabiting and which are sometimes confused with wireworms. They are the Crane Fly, or Daddy-Long-Legs, and certain moths including the Turnip Moth. The larva of the crane fly is the leather-jacket, while the name 'cut-worm' is given to the caterpillar of the moths. These larvae, unlike wireworms, do most of their feeding at soil level, and it has been found possible to poison them fairly easily by means of an attractive bait made of a mixture of Paris Green (a substance containing arsenic) and bran, or dried sugar beet pulp. About 1 lb. of Paris Green mixed up with 30 lb. of moistened bran can be scattered over an acre of threatened crop, and in warm, not too dry weather, large numbers of the larvae can be destroyed through eating the poisoned bait.

Slugs, which are sometimes a very serious pest in fields and gardens, can also be attacked with Paris Green bait, but quite recently a substance much more deadly to slugs has been used. This is metaldehyde, a substance which enters into the composition of the solid fuel sold for use with camp stoves. It was discovered that metaldehyde, mixed with bran, is extremely attractive and very deadly to slugs, whilst it is probably less dangerous to use than Paris Green. It is, however, ineffective against leather-jackets. The bait is composed of one stick (about 4 grammes) of the proprietary fuel to two pints (about ½ lb.) of bran.

Whilst the intelligent use of rotations may do a great deal to prevent or minimize attack by pests, the study of the life histories of the pests themselves sometimes indicates that cultural methods may be adapted towards insect control. The Frit Fly which attacks spring oats is an example. The female lays her eggs on the young oat plant during May, and the larvae feed upon the central shoot. This is destroyed, and though lateral shoots, or tillers, may develop, the crop is much reduced. Sub-

sequent broods of flies may attack the developing grain. The younger the oat plant at the time the flies emerge the more it is damaged. Early sowing is one of the greatest safeguards against this pest, and February sown oats are much less likely to suffer serious damage than oats sown in April.

The frit fly problem illustrates, too, another method which is being used to combat insect and allied pests. This is the breeding of resistant varieties. Obviously, if a variety of oat could be obtained entirely resistant to attacks by the frit fly, the problem, so far as this pest is concerned, would be solved. Unfortunately, however, it does not follow that resistant varieties are good croppers, so that the problem is to obtain resistance combined with good quality and yield: it is too early to speak of commercial results.

Another example of how the study of the life cycle of an insect pest can assist the farmer is provided by the Wheat Bulb Fly. The first signs of the presence of this creature on the farm is the yellowing in April of the central shoot of winter wheat plants. Examination of attacked plants discloses a small white grub, distinguishable from that of the frit fly by its much greater size. The damage to a crop may be very severe, and by the time it is first noticed it is far too late to do anything about it. For the grub comes from eggs laid by the female fly in late July and the eggs, astonishingly, are always laid on bare ground, preferably when this is in a dusty state. Now in July most of the soil in the average farm is occupied by and covered by crops of various sorts. How then, can a whole field of wheat be devastated by the grub of a creature which lays its eggs on bare ground? The answer, of course, is that attacks of wheat bulb fly are severe usually when the wheat is autumn sown after a bare fallow. In a bare fallow, which is practised on stiff heavy soils to clean them of weeds, the land is left for a whole season without a crop. It is ploughed repeatedly, and stirred with cultivators, from May to August or September. At first the land is purposely broken up into huge, rough clods to bake any creeping grasses and so forth, but as the months pass the tilth becomes progressively finer, so that by July and August the female wheat bulb fly dis-

covers excellent conditions for egg laying. The grub which hatches from the egg later bores into the seedlings of wheat planted in late summer, with the results already described. A similar sort of thing may happen in a field of turnips or mangolds where the crop is very poor and the soil is left bare.

It is clear, then, that only after a bare fallow—or possibly a bastard or half-fallow following peas or a ploughed-up ley—is wheat bulb fly likely to affect autumn sown wheat at all seriously. Knowing this the farmer can either take a risk and do his fallowing in the traditional way: or he can work his soil down a bit earlier and plant the land with mustard in July, so getting a cover of foliage by August before ploughing in the mustard in advance of wheat sowing; or he can leave a very rough surface to the very latest time, since the fly apparently does not appreciate such conditions for egg laying. Or, in place of wheat he may sow winter beans, which are not attacked by the pest; or he may compromise by planting a 'mixed crop' of beans, wheat and possibly oats.

Gardeners have long been familiar with the insect pest called Black Fly which regularly attacks the tips of broad bean plants. The creature does not confine itself to gardens, but also feeds upon such farm crops as sugar beet and mangolds: in some seasons the damage caused may be very considerable. Not only the crop grown for sugar but also the crop grown for seed is liable to attack, and in the seed growing areas of the Eastern Counties, black fly is a dangerous enemy. The insect, of course, is an aphis which lives on the sap of plants which it sucks up through its sharply pointed, tubular mouth parts. Like many other of the aphis tribe, the female in spring and summer is able to produce living young (i.e. the egg stage is cut out) and this leads to the very rapid rate of multiplication so characteristic of the black fly. Another interesting feature is that all the spring and summer broods are composed of females only, for the male does not appear until the autumn, when the winged females fly off to their winter quarters. Here, after fertilization, the female lays her eggs, and it is from these over-wintering eggs that the primary infestations of the following spring are spread.

As a rule this aphis overwinters on bushes of the common European Spindle (*Euonymus europaeus*), and it has been found that there is a correlation between the number of winter eggs on this plant and the intensity of the primary infestation on sugar beet in spring. It is now a routine business for the appropriate entomologists to study the Spindle bushes in winter and to form, months in advance, an estimate of the probable intensity of black fly attack upon sugar beet in the coming season. If, owing to the large numbers of overwintering eggs observed on the bushes, a heavy infestation in spring seems likely, a warning to growers is issued so that the crops can be carefully watched and the initial infestation dealt with promptly. The most efficient method of dealing with black aphis on sugar beet is by fumigation with nicotine vapour, using a drag sheet.

Great advances have been made in the control of carrot fly since it was first shown that the insect shelters in hedges and rough undergrowth, emerging therefrom to lay its eggs on the ground close to the carrots, and returning to shelter again. The adult carrot fly is easy to recognize once its peculiarities have been pointed out; it is consequently a comparatively simple matter for an intelligent person to 'sweep' the base of hedgerows around a field of carrots with an entomological net and to decide if the infestation of flies is sufficiently severe to threaten the crop. If it is, the next procedure is to spray the surrounds of the field with a poison bait consisting of a weak sugary solution containing sodium fluoride, or better still with DDT which has a more lasting effect. This treatment begins, in the Eastern Counties, between the middle of April and the middle of May, when the first generation of flies is on the wing. More than one spraying may be needed to destroy all the flies of this brood. The second generation of carrot flies appears in August and September, so the sprayings are repeated at this period.

The gassing of insect pests on a field scale is now a regular practice in parts of the country. The pests most commonly attacked by gassing are various aphides which damage cooking peas, strawberries, brussels sprouts and cabbage. The apparatus used consists of a tractor-mounted gassing machine, which

vapourizes nicotine and injects it under a large dragsheet, 40 ft. wide and 100 ft. long. The tractor progresses at about one mile per hour, so that the nicotine vapour remains in contact with each plant for an appreciable time, destroying almost all aphides, but doing no serious damage to their parasites, the ichneumon flies and ladybird insects. An interesting feature is the extremely little damage done to the crop plants by the passage of this apparently cumbersome implement.

Some very valuable new insecticides have been developed during the past few years, of which DDT and benzene hexachloride are the most important.

Dichloro-diphenyl-trichloroethane, which is almost always referred to as DDT, was first prepared in 1874, but no use was made of it until it was re-discovered and its insecticidal value recognized about 1939. It is a white solid which will not dissolve in water but which is soluble in various other liquids including certain oils. It has a paralysing effect upon many insects which come in contact with it, and it also behaves as a stomach poison. One of its most useful properties is that it retains its toxicity very much longer than most insecticides—it may be capable of killing insects weeks after it has been sprayed upon walls, etc., under cover, while in the open it remains lethal for several days. The first spectacular success achieved by DDT was during the typhus epidemic in Naples in 1944: the whole population was dusted with the powder form to destroy lice which are the transmitters of typhus. Human beings and domestic animals are not affected by DDT at the concentrations likely to be used normally, nor are all insects susceptible to it. Lice, fleas, house flies, root flies, flea beetles, apple blossom weevil are soon killed by DDT, but other species are resistant. DDT is of limited use as a controller of soil insects as it does not volatilize in the soil. There is also a growing body of evidence that immunity to DDT can be rapidly built up by some insects such as house flies, and this may seriously limit the value of DDT as time goes on.

At about the same time that DDT was re-discovered British scientists developed another remarkable insecticidal substance called benzene hexachloride. This material, BHC, also called

hexachlorocyclohexane or '666' from its chemical formula CH Cl_6, exists in a number of different forms or isomers in which the component parts are differently arranged. Only one arrangement or isomer is deadly to insects, the 'gamma' or third isomer, gamma hexane, which has recently been given the name 'lindane' after its discoverer, Van de Linden: the proprietary name 'Gammexane' reflects this construction. Benzene hexachloride behaves very much like DDT so far as killing insects is concerned, but it has also proved useful as a soil insecticide, especially in controlling wireworms. A broadcast dressing of about 2 cwt. per acre of a dust containing about 5 per cent benzene hexachloride appears to give immunity from attack to cereals, while more recently the combine drilling of ½ cwt. per acre with cereal seed has been successfully practised. The most recent development of all is the treatment of grain with lindane in conjunction with the organo-mercury dusts which have long been used to destroy seed-borne fungi (see p. 123). Enough of the insecticide is caused to adhere to the grain to protect both it and the seedling from insect attack; this development is still in the experimental stage. A disadvantage of BHC is its liability to impart an unpleasant taste or taint to food crops like the potato or carrot, and this naturally limits its application: the taint may persist in the soil for two or even more years.

The introduction of DDT and BHC has put a powerful weapon into the hands of the farmer who is troubled with the turnip fly. When turnips and swedes were much more widely grown than they are now the early spring was an anxious time, since the turnip fly—which is really a 'flea-beetle'—could suddenly appear in large numbers and completely destroy the seedlings almost as soon as they appeared above ground. Although it was well understood that a properly prepared seedbed assisted the plants to 'grow away' from the fly, and that the application of some dusty substance like basic slag or lime might mitigate the severity of an attack, yet on a hot dry day the farmer all too frequently had the mortification of witnessing the disappearance of his crop despite his every effort. In recent years the kale crop has suffered most, since this plant has largely replaced

turnips in English farming. It is now possible to protect brassica seedlings of all types by the use of dusts containing about 5 per cent of either DDT or benzene hexachloride: as already mentioned, these compounds retain their toxicity for long periods, so that a single dusting may give ample protection to the seedlings during the especially vulnerable stage, which is between the appearance of the cotyledons and the development of the first rough leaves. About 40 lb. per acre of the protective dust are usually required, and this can be applied either by shaking a muslin bag over the rows of seedlings or on large areas by simple home-made shakers of wood towed behind a horse.

During the 1939–45 war there was a great shortage of nicotine for insecticidal purposes, and in Germany there was developed an organo-phosphorus compound called 'Bladen', consisting in part of hexaethyl tetraphosphate, called for short HETP. This won official recognition in 1944 for use as a nicotine substitute against aphides, and since then has been extensively studied both in Europe and America. Like nicotine it is very poisonous, but because it is volatile it is non-persistent and leaves no poisonous residue. HETP is a mixture, the most active constituent of which is tetraethyl pyrophosphate, which is present to the extent of up to 20 per cent. A new form of the original mixture, containing about 40 per cent of tetraethyl pyrophosphate is now available, and has been given the name TEPP.

Another discovery made in Germany by Schrader is that certain water-soluble compounds applied to the soil can be taken up by plants, rendering the latter resistant to attack by insects. Materials which behave in this way are called systemic insecticides. Certain derivatives of phosphoric acid and some fluorine compounds are known to act in this way, and both aphides and caterpillars feeding on plants watered with or sprayed with systemic insecticides have been destroyed. One of the best known of these compounds was developed in Germany; it is a form of nitrophenyl diethyl thiophosphate, and was originally called 'E.605'. It has now been christened 'parathion'.

Another substance which has been used on a commercial scale is Bis(dimethylamino) phosphonous anhydride. If sprayed on

foliage, the material causes the plant to become toxic to sap-feeding insects and mites for periods up to ten weeks: but the plant remains non-toxic to pollinating insects and to insects which prey upon aphides. The compound has so far been used mainly on hops, the rate of application being 1 lb. per acre dissolved in water. It is claimed that two suitably timed applications will keep hops free from aphis attack throughout the season. Obviously these are materials to be used with the greatest care because of their possible poisonous effects upon stock and human beings, but their scientific interest is very considerable.

COLLATERAL READING

The best introduction to farm pests is probably S. G. Jary's *Good Control of Insect Pests* (E.U.P., 1948), and the reader's studies can be continued with A. D. Imms's textbook, *Outlines of Entomology* (Methuen, 1942). *Agricultural Entomology*, by Kenneth Smith (C.U.P., 1948) deals with all the common farm insects, while C. L. Walton's *Farmer's Warfare* (Crosby Lockwood, 1947) tackles other pests as well in a less formal way. *Pests of Farm Crops*, by J. H. Stapley (Spon, 1948) is a recent addition to the literature. *Biological Control of Insects*, by Hugh Nicol (Penguin, 1942) contains much matter of interest to the specialist farmer. The leaflets of the Ministry of Agriculture dealing with individual pests are continually being revised and brought up to date.

Chapter Six

PLANT DISEASES

Importance and cost of fungus diseases—yellow rust—nature of fungi—wart disease of potatoes—immune varieties—legislative control—potato blight—Bordeaux and Burgundy mixtures—burning-off with sulphuric acid—dry rot—virus diseases—nature of a virus—financial losses due to virus diseases—leaf roll and mosaic diseases of potatoes—distribution by aphides—superiority of Scotch and Irish seed potatoes—seed potato growing in North Wales—virus yellows of sugar beet—clover rot—seed-borne diseases—bunt in wheat—method of infection—disinfection of seed—copper sulphate—formalin—disadvantages of wet disinfectants—powdered copper carbonate—loose smut and the warm water treatment—use of compounds of mercury—leaf stripe in oats—take-all and whiteheads—eyespot disease—spray fluids.

The most important diseases of farm crops in this country are caused by fungi. Bacteria, and those little understood agencies called viruses, also attack farm plants, but they are not usually so destructive as the fungi.

Plant diseases are very expensive, both to the individual farmer and also nationally. They have even had, in the past, important political consequences. The failure of the potato crop in Ireland, about the middle of last century, brought about by the 'blight' fungus (*Phytophthora infestans*), led to widespread famine and misery, depopulated Ireland, and caused the immigration into Liverpool, Glasgow, and the United States of America of hundreds of thousands of Irish. Such a calamity as this

famine cannot fail to impress upon the minds of everybody the potentiality for evil which certain fungi possess; but in less spectacular ways fungus enemies take a tremendous toll upon food production, leading to losses which are none the less real though often unsuspected. It is said, for example, that the common yellow rust of the wheat plant every year diminishes the yield of the crop from 5 to 10 per cent. That is to say, the nation loses about 150,000 tons of wheat every year from this disease alone. In these days, when the production of more and more food at home is regarded as a national necessity, such a wastage cannot be ignored, and it becomes a matter of general interest to learn something about plant diseases and the methods which are being used to fight them.

Fungi are remarkable things, both in their variety and mode of life. They range from the tiny yeasts which cause fermentation to the large toadstools so common in fields and woods. They all agree in having no green colouring matter or chlorophyll; and this characteristic prevents them from making their own food in the way that green plants synthesize it from the carbon dioxide of the air and the mineral matter of the soil. Fungi must get their food from living or dead animals or plants; if the first, they are called parasites; if the second, they are called saprophytes. It is the parasitic fungi which cause plant disease, but it should be remembered that many non-parasitic fungi are very useful in agriculture, since they cause decay, or rotting, of farmyard manure and other organic matter, without which farming would eventually become quite impossible.

In the fight against plant disease science has to proceed in an orderly fashion. First of all the cause of the trouble has to be identified, and this is not always easy, because the parasitic fungus may be accompanied by non-parasitic species, and their separation offers difficulties. Then the mycologist (the man or woman who studies fungi) has to trace out the life history of the parasite, find out how it is spread, and then think out how best to attack it.

Take the case of the Wart Disease or Black Scab of potatoes Round about 1902 it became known that potato growers in

parts of Shropshire and Lancashire were becoming seriously alarmed on account of a disease which attacked the tuber. Instead of nice clean potatoes they were digging up badly warted tubers having large, cauliflower-like excrescences of a brownish or blackish colour. At first these 'warts' were firm and hard, but soon the whole potato rotted down into a shapeless mass. The losses in certain parishes were very considerable. Investigations showed that a lowly form of fungus, named *Synchitrium endobioticum*, was responsible. It lives in the outer layers of the potato tuber, which are distorted into the 'warts', and it not only forms thick-walled resting spores in the tuber, but it also releases other spores into the soil. Both kinds of spore can spread disease. It was found, also, that these spores are very long lived, so that even if potatoes were not in the land oftener than once in eigth years, the possibility of the complaint cropping up again with the next planting could not be ruled out.

This was a very serious state of affairs, especially as the disease was rapidly spreading with the distribution of infected seed potatoes. It appeared at one time that the cultivation of potatoes in infected soils would become impossible, since no practical method of sterilizing farm soils was forthcoming. It was noticed later, however, that different varieties of potatoes reacted differently to the disease when grown on infected soil. Most varieties developed the warts on the tubers, but a few yielded perfectly clean potatoes. This simple observation—and it should be remembered that science is largely systematic observation—led to the control of the disease, for it was later made quite clear that some potato varieties, such as Kerr's Pink, Great Scot, and Majestic, are entirely immune. These varieties can be grown on wart-disease infected soil without contracting the complaint, but obviously it would be very unwise to use such potatoes as seed on non-infected land, because of the danger of spreading the spores.

Consequently, for the protection of potato growers generally, the Ministry of Agriculture, under the Wart Disease of Potato Order, 1923, have made it compulsory for growers to notify the police if the disease appears in a hitherto uninfected area. The

growing of non-immune varieties in infected soil is forbidden, and seed potatoes from an infected crop may not be offered for seed purposes.

The testing of new varieties of potatoes—and dozens of these were sent for trial every year—for susceptibility to wart disease became a very important branch of work carried out for many years by the National Institute of Agricultural Botany at trial grounds situated at Ormskirk, in Lancashire. The trials are now conducted in association with the University of Nottingham School of Agriculture near Loughborough. A laboratory method of testing new varieties for susceptibility to wart disease has superseded the older method of field trials.

Wart disease is not the only serious complaint that the potato grower has to contend with, and for which he seeks the aid of the scientist. The Blight, or 'potato disease' fungus has already been mentioned, and it still is one of the most serious farm diseases. Modern science has so far been able to suggest no better means of controlling the fungus than spraying with Bordeaux or Burgundy mixtures, or other compounds containing copper. The Bordeaux mixture dates from about 1882, and is a combination of copper sulphate and lime. The usual method of preparation is to dissolve 12 lb. of copper sulphate in water, add 6 lb. of freshly slaked quicklime, and make up with more water to 120 gallons. This is sufficient to spray one acre of potatoes. Sometimes the mixture is made double this strength. Burgundy mixture dates from 1887, and 15 lb. of washing soda are substituted for the lime. The chemistry of these two mixtures has received a great deal of attention but is still not properly understood. It appears that a very fine precipitate of a copper compound is formed when the mixture is prepared, and when this is sprayed as a fine mist upon potato plants, a thin layer covers the surface of the leaves. This layer is toxic to the developing spores of the disease fungus, and so protects the plant from invasion. More recently ready-made proprietary compounds containing 'organic' copper have been introduced, but their efficiency seems to be no greater than that of the original prescription. Spraying potatoes with any of these preparations

is, of course, entirely a preventive measure. Modern science has not yet discovered any means of curing a plant once the fungus has made its entry; nor has it yet been able to breed a satisfactorily yielding potato which is immune to blight, though some progress has been made in this direction during the last ten years (see p. 62).

It was discovered not so very long ago that most tubers become contaminated with the fungus of potato blight during the harvesting of the crop. If lifting is carried out while the haulm (or tops or shaws as they are variously called) is still green, countless numbers of spores are shaken off the leaves and settle upon the tubers as they lie exposed upon the surface of the soil. Contamination of this sort can be minimized if the tops are allowed to die down completely before lifting is begun, for the spores by that time will all have been shed. But it is often inconvenient to wait for this dying down, especially with late-maturing varieties like Dunbar Standard. So the practice has arisen of 'burning-off' potato tops several days or even weeks before the crop would die down normally. The material used is generally 10 per cent sulphuric acid applied at 100 gallons per acre, for this has been found more efficient than any of the other recommended substances such as sodium chlorate or tar products. The acid destroys many spores and also kills the tops so that few spores remain in them after a few days. This acid spraying has other beneficial results of considerable economic importance: harvesting is more rapidly performed because the tops are no longer a nuisance through choking the spinner or digger, and weeds are greatly reduced. Seed potato crops which are lifted in an immature condition, are frequently sprayed with sulphuric acid to prevent disease and to facilitate harvesting.

Another serious disease of potatoes is Dry Rot, caused by the fungus *Fusarium caeruleum*. This organism lives in the soil and usually infects the tuber via cuts and bruises caused by rough treatment at harvest, in transport or in storage. The disease is of great economic importance to growers and users of seed potatoes; for example, the variety Doon Star which has many admirable qualities, has quite lost its one-time popularity

because of its susceptibility to dry rot. In some seasons the fungus may render useless a large proportion of otherwise good seed which has to be rejected before planting, while infected seed, if planted, gives a poor crop. A few years ago it was discovered that the disease could be controlled if seed potatoes were dipped, immediately after lifting, in a 1 per cent solution of formalin, or better still, an organic mercury dip. More recently still it has been found that dry rot can be controlled to a considerable extent by powders containing chlorinated nitrobenzene, as described on page 192. The dipping of potatoes is a relatively slow and expensive operation which can only be justified if the seed has special value: nevertheless it gives a very nice sample of seed and is practised by numerous growers.

Scientific interest in potatoes has rather shifted to the problem of virus diseases, which are very harmful to the potato and also to other plants of less farming importance. It has long been realized by lowland farmers that if they save their own 'seed' potatoes and plant them year after year on their own farms, the yield gets smaller and smaller. The seed 'degenerates', and fresh seed from a different locality must be obtained if profitable crops are to be grown. Until recently this degeneration of potato stocks could not be explained, but investigations, particularly since the war, show that it is due, to a large extent at any rate, to virus diseases.

A virus disease may be defined as 'an infectious disease caused by something which cannot be seen under the highest powers of the ordinary microscope'. These complaints occur in animals as well as in plants, for foot-and-mouth disease in cattle, smallpox and scarlet fever in human beings are due to viruses. It is uncertain whether a virus is a soluble substance similar to an enzyme, or a separate living organism like a bacterium. Whichever it may be, a virus is capable of passing through the excessively tiny pores of an unglazed porcelain filter which would retain with ease the smallest known bacterium; hence the term 'filterable virus', so commonly used. Another characteristic of most viruses is their inability to multiply outside the cells of the plants or animals which they normally inhabit.

The financial losses caused by viruses in animals need no stressing; some outbreaks of foot-and-mouth disease have cost the country several hundreds of thousands of pounds. Virus disease in plants may not be so spectacular, but the losses due to them are very considerable. The loss in yield of the potato crop in North Wales due to leaf roll alone, was for several years estimated at about 50 per cent, and in Lancashire and Cheshire the losses from the same virus were at one time put as high as 61 per cent—the financial loss in some instances amounting to over £5 per acre.

So far as the potato crop is concerned, the worst virus diseases are 'Leaf Roll' and 'Mosaic'. In leaf roll the leaves begin to roll upwards from the edges, starting at the base of the leaf. They also become thickened, harsh, and leathery to the touch, and starch accumulates. The degree of rolling varies in different potatoes, and it may or may not be accompanied by changes in colour. 'Mosaic' diseases are not so easily described, because there are so many different forms. It seems quite clear that several different viruses cause different kinds of mosaic diseases, but unfortunately the same virus is capable of giving rise to different symptoms in different potato varieties. This makes the study of the viruses very difficult, and has led to much confusion in the past. Kenneth Smith states that the potato virus Y is one of the commonest and most destructive viruses in the country. It gives rise to a blotchy mottle which spreads from the veins of the leaf, the veins turn brown, and eventually the whole leaf collapses. Potato virus A is similar in some ways to virus Y and is also transmitted by insects. Potato virus X causes mild mosaic: it is not transmitted by insects, but by contact between leaves of diseased and healthy plants. In other mosaic diseases the mottling may be accompanied by yellowing and crinkling. It has been stated that 90 per cent of the potato stocks of England are infected by mosaic of one form or another.

All virus diseases of the potato can be spread if a healthy plant be grafted into an infected plant, and vice versa. Many virus diseases can be inoculated into a healthy plant if a drop of sap from an infected plant be scratched into the tissues of a

healthy plant with a needle. Leaf roll, however, cannot be artificially spread in this manner. In nature, inoculation is performed by certain small insects, the most important of which is one of the aphides (greenfly or plant lice) called *Myzus persicae.*

When an aphis of this species sticks its slender, tubular, sucking apparatus into a virus-infected potato plant and sucks up the sap, the virus comes along as well. If the aphis then begins to feed upon another, virus-free plant, its saliva introduces the virus into the fresh puncture, and the damage has been done—inoculation has taken place. This procedure can take place not only on plants growing in the field as a crop, but also during the winter months in seed tubers set up for sprouting.

Potato growers in England have for many years obtained their seed from Scotland or Northern Ireland, because experience has shown that these stocks are less likely to show signs of degeneration than the English stocks. The relative freedom of Scotch and Irish seed potatoes from virus diseases is attributed to a relative scarcity of virus-carrying aphides. The Scotch and Irish seed potato industry is a very important one. It is important to the seed growers themselves, and it is valuable to farmers in England who require good seed if they are to make a profit from their own crops of cooking potatoes. A bigger supply of better seed would obviously benefit the whole industry.

As an example of the way in which the new knowledge of the inter-relation between virus and aphis has been applied, the development of the seed potato growing industry in North Wales may be quoted.

First of all the investigators (the Agricultural Department of University College, Bangor) had to find out in what areas the spread of virus diseases was slowest. These areas were found to possess only scanty populations of aphides compared with other areas in which degeneration was rapid. Experiments extending over nine years showed that stocks grown in these areas cropped as well as imported Scotch seed. The next thing was to try out the scheme commercially. Farms in approved areas were selected, and all the farmers' potatoes, no matter how vigorous they might appear, were completely removed lest they might be virus in-

fected. The farms were restocked with seed authorized by the College, and the crops were inspected at least three times during the growing season, any suspected plants being at once removed. Seed from the stocks was placed in special bags. The seed was found to be of such high quality over a number of years that in 1935 the Ministry of Agriculture put Welsh seed on a level with Scotch and Irish seed. By 1936 over seventy growers in North Wales were producing some 250 tons of virus-free seed potatoes under the supervision of the College. Good stocks of potatoes are now being produced in Cumberland and Westmorland as well as in other parts of the country.

The success of the scheme points to a solution of the virus disease problem in potatoes. Of course, the North Wales scheme was assisted by the fact that potatoes in that district are usually grown in small isolated patches, but the first requisite is an area which has a low infestation of the virus-carrying aphis. The discovery of the relationship between the number of certain aphides and the size of potato crops is one of the romances of modern scientific agriculture.

A 'seed' potato is, of course, not a true seed but a swollen underground stem; nevertheless it is always spoken of as seed, and for our immediate purpose may be considered as such. The control of potato degeneration has been shown to be a matter of controlling the 'seed': by sowing clean and non-infected seed a good crop for one or two years may be reasonably expected.

A virus disease of considerable importance is virus yellows of sugar beet and mangolds. In this complaint the leaves turn yellow and become very brittle and the yield may be very seriously reduced. Here again the virus is spread by insects, the potato aphis and the black bean aphis. Nothing can be done to cure plants attacked by the virus, but fortunately the disease is not transmitted in the seed. All that the ordinary farmer can do is to sow his beet as early as possible and to destroy all sources of infection such as 'volunteer' plants of sugar beet or mangolds: it is by first feeding upon infected volunteer plants and then moving in to the crop that much infection is started. In districts where sugar beet and mangolds are grown for seed it is essential

that the 'stecklings' or young seed plants shall be as far away from sugar beet crops as possible, and measures have been devised for spraying the stecklings with nicotine or derris to kill any aphides which may be present.

Other virus diseases are mosaic disease of cauliflower, and black ring spot in broccoli: no control of these has yet been discovered. The tomato, of course, suffers from many virus diseases, including mosaic, streak, and spotted wilt: the hop is another great sufferer. The study of viruses is relatively new: it is extremely complicated and much more difficult than the study of diseases caused by fungi and bacteria.

It was stated on page 79 that red clover has had a profound influence upon rural and national life; nevertheless its value to the farmer is limited by its susceptibility to a disease called clover rot. This is due to a soil-borne fungus which causes the foliage to turn brown, then black, and finally to rot away. The appearance of small black bodies, varying in size from a pin's head to a pea, is proof of the presence of the fungus, *Sclerotinia trifoliorum*. It must be confessed that science has done little with this disease organism beyond naming it, describing its life history, and agreeing with the old observation that the best way of controlling it is to keep red clover from following red clover too frequently. A wide rotation, in which red clover is sown only every eight years is now recommended, sainfoin, alsike clover, white clover or trefoil being used in the intervening years. Occasionally an eelworm may cause 'sickness' in red clover, and prevention here is also a matter of a wide rotation.

Quite a number of important crop diseases are spread by seed, and during recent years very great advances have been made in methods of controlling these. The most important seed-borne diseases of farm crops are Bunt, or Stinking Smut, of wheat; Smut, of barley and oats; Leaf Stripe, of barley and oats; and Black-leg, of sugar beet and mangolds.

In order to show how the control of these diseases is being achieved, the case of Bunt of wheat may be considered in some detail. Just before harvest the ears of wheat may be found to contain not normal, healthy grains, but grains filled with a dark

powdery substance, smelling of rotting fish. These grains are obviously useless for food, and they may also render objectionable those healthy grains with which the bunt dust, or spores, comes in contact. The disease has been known for thousands of years; bunted wheat was spoken of as being 'blasted' or suffering from a distemper, and in the days when famine was a frequent visitor to civilization, the incidence of bunt was very understandably attributed to divine wrath. It was not until about 1800 that the black dust of bunt was shown to be composed of countless numbers of individual fungus spores.

From the middle of last century the life history of the fungus has been well known. The spore dust liberated by the bursting of infected grains sticks to the outside of healthy grains, particularly along the furrow and amongst the hairs at the top. When this contaminated seed germinates so do the spores, and the fungus grows along with the wheat plant until it finally enters the developing grain and forms its dark brown spores. Until this happens it is not possible to tell that the plant is infected by the parasite.

Even before the cause of the disease became known, crude attempts were made to disinfect seed wheat before sowing, in the hope of reducing the serious losses caused by bunt. Students of old agricultural journals, magazines, and books published 150 or more years ago will find much interest and some amusement from descriptions of old-time methods of 'pickling' seed wheat. Extraordinary mixtures were recommended usually consisting of the most evil-smelling substances available. Soot, salt, chamber-lye, extracts from manure heaps, and so forth—most of them of very little fungicidal value—were used, but with very little benefit. The only substance to give any control was copper sulphate, or bluestone, and during the middle of last century this became the standard dressing against bunt.

Unfortunately, in the strengths usually used to kill the bunt spores, the copper sulphate has a bad effect upon the germination of wheat, especially if the grains are at all damaged or cracked. But until as recently as 1920 copper sulphate solutions in concentrations of from 1 to 10 per cent were almost exclusively

used in this country for the control of bunt. In 1921 a new method of disinfecting wheat grains with weak solutions of formalin was devised. It was shown that, if properly carried out, the formalin method not only kills the fungus spores more efficiently than copper sulphate, but has no ill effects at all upon germination. In a few years the formalin method had almost ousted the copper sulphate treatment.

But treatment with formalin solutions, though effective, suffers from disadvantages common to all watery disinfectants. Fluids cause the grain to swell, and this may affect its delivery along the spouts of the drill; wet grain must be dried before it can be sown, or it sticks together in a mass; and most important of all, the grain must be sown within about twenty-four hours of treatment, or it loses its vitality to a tremendous degree. The farmer cannot control the weather, and conditions immediately after 'pickling' has been performed may make it impossible to drill the seed. For these reasons a dry disinfectant powder was much to be desired.

About 1917 finely powdered basic copper carbonate was used by Darnell Smith in Australia to control bunt. He found that about 2 oz. well mixed up with a bushel of grain destroyed the spores without damaging germination. Treated grain could be stored indefinitely without losing its vitality. This discovery was not appreciated at its full worth for another ten or twelve years, partly on account of the first world war and partly because of the success of the new formalin treatment just described. About 1928 the copper carbonate dust method of seed disinfection was taken up with enthusiasm by seed firms, some of which arranged to send out seed wheat already treated with the powder. From a practical point of view this was a great advance, and for the first time in the cultivation of the wheat crop the farmer felt safe in neglecting to pickle his seed. Copper carbonate is poisonous if breathed in in quantity, but a pad of cloth over the user's mouth is all that is needed to protect an operator. Thorough mixing of seed and disinfectant dust is very necessary, but it was soon found that an old end-over-end butter churn makes a very useful mixer for use on the farm, and in a very short time a number of these converted churns were being used by farmers who

preferred to dress their own seed wheat. Copper carbonate dust has now been superseded by other dry disinfectants, as will be shown later.

Bunt, or Stinking Smut, has been dealt with at this length in order to show what rapid developments have taken place in the control of seed-borne diseases. Of course there are other seed-borne smuts—there is the loose-smut of wheat and barley, for example, in which the whole ear may rot away into a black powder. Science is at the moment baffled by these two diseases, because the fungi which cause them are hidden deep within the seed itself. They cannot be destroyed by external pickling; it is possible to kill the fungus by immersing the seed for four hours in water at a temperature of 52–54 degrees C. (125 to 129 degrees F.) without killing the grain, but practical difficulties make it almost impossible to use the method on the farm. The best precaution against these diseases is to sow seed which is known to have come from a clean crop. Then there are other seed-borne diseases such as the Smut of oats, Leaf Stripe of oats and barley, seedling Blight of rye, and Black-leg of sugar beet and mangolds.

Those who know anything about germicides might wonder why mercuric chloride, popularly called corrosive sublimate, has not been mentioned as a seed disinfectant. Early experiments with this substance, carried out about 1890, gave poor results in controlling smuts of cereals, and it was not until 1915 that the possibilities of the compound were realized. It was then discovered in Germany that mercuric chloride would control the fungus responsible for seedling blight of rye. This was a valuable point, because the fungus which causes seedling blight lies actually within the seed. There are no spores on the outside of the grain as in the case of bunt, and it seems probable that the mercuric chloride lies in wait, as it were, for the fungus to start growing during the germination of the seed before it attacks and destroys it.

Mercuric chloride is so very poisonous that other mercury compounds, described as organo-mercury derivatives, were experimented with. The preliminary work on these was almost entirely carried out in Germany by commercial firms, and the

substances themselves became known only under their trade names. 'Uspulun' consisted of 'chlorphenol-mercury' plus sodium hydro-oxide, and was used as a wet steep or pickle. The success of the dry copper carbonate dust, however, led to developments of dry organo-mercury powders. These mercury compounds were soon found to be even more efficient than copper carbonate in disinfecting seed and in this country have quite ousted the copper compound. Not only do they prevent bunt in wheat, the smuts of oat, and covered smut in barley, but they also control leaf stripe in barley and oats. Leaf spot and leaf stripe, or Helminthosporium disease of oats, had become an extremely destructive disease, notably in certain parts of Scotland, causing very considerable losses. The crop may die off badly in the seedling stages, or later may develop long brown stripes on the leaves followed by a partial or complete failure of the ears to develop. Until the development of these organo-mercury dusts the disease could not be controlled, but now it is possible to disinfect the seed before sowing and so get satisfactory crops. The cost of treating cereals usually amounts to only a shilling or so per acre, and treated seed can be stored for a long time without being damaged. Like copper carbonate, these dusts are poisonous and must not be inhaled.

Since 1939 there has been an urgent demand for home grown wheat, and in recent years production, especially on lightish land, has suffered because of the attacks of two fungus diseases which previously received scant attention. In one disease patches of young wheat appear to be stunted and generally unhealthy, and when the ears begin to emerge the plants may die off, or if they do manage to form grain this is shrivelled and worthless. The complaint is called Take-all or Whiteheads, and it can be distinguished from unhealthiness due to manurial deficiency by the appearance of the base of the stem; this takes on a characteristic blackened appearance, and the roots are grey in colour and break off easily. The behaviour of the fungus (*Ophiobolus graminis*) has been very carefully worked out by Garrett, who has shown that it lives on root or stubble remains of wheat and barley and certain grasses, notably couch grass,

bent-grasses and Yorkshire Fog. He has shown, too, that the fungus is not an absolute killer—that is, a well-nourished plant can survive an attack if it can grow new roots faster than the fungus can destroy them. Further, if the soil is well consolidated the fungus has difficulty in spreading. Armed with this information about the habits of the fungus, it is possible for the scientist to suggest means of preventing and overcoming take-all disease. The obvious thing is to avoid a continuous sequence of wheat crops, or of wheat followed by barley, which is also attacked by the fungus. This has not always been possible recently because of the drive for grain acreage. Oats are not susceptible to the common strain of the fungus and can be used, as can a non-cereal crop, to break the cycle. If autumn planted wheat must follow wheat or barley, then planting should be delayed as long as possible to reduce chances of seedling infection and the land should be well consolidated. Then in spring, if symptoms of take-all appear, damage can be minimized by applying a top dressing of some nitrogenous fertilizer to encourage growth, and root growth in particular.

The other complaint which has become common in wheat and barley is a serious lodging or laying in which the straws 'straggle' or 'go down' in all directions. This is quite different from the lodging due to excessive nitrogen or high soil fertility, where the straws fall usually in one direction. The cause of the straggle form of lodging is a fungus, *Cercosporella herpotrichoides*, and the disease is called Eyespot because of the oval, eye-shaped, brown areas which develop on the lower leaf sheaths and basal parts of the straw. Infection takes place by spores which spread in rain drops: in fact, moist conditions greatly favour the development and spread of the eyespot fungus, and the complaint is worst in heavy soils. Here again a system of crop rotation which leaves a gap in time between wheat and barley crops is the obvious way of reducing losses by eyespot, and usually it takes more than one season to clear up the infection; it appears that dung made from infected straw can spread the disease.

In the Fen districts where winter-planted wheat often grows very rank in the spring, crops are sometimes sprayed with 10 to

12 per cent sulphuric acid to reduce the 'flag', and it is said that this also reduces eyespot infection by destroying the fungus on the plants. Drilling too much seed to the acre crowds the plants together and produces humid conditions favourable to the spread of the fungus. These two fungi provide examples to show how complicated modern farming may become since striving for maximum production per acre frequently leads to growing conditions highly favourable to crop enemies.

During the last thirty years a great deal of attention has been paid to the control of fungus diseases by means of spray fluids. On the average farm very few of these sprays are ever used, but for the protection of fruit and horticultural crops this branch of modern science is of ever-increasing importance. Information concerning the fungicidal sprays, which hardly come within the scope of this work, can be obtained from books mentioned at the end of this chapter.

COLLATERAL READING

A fascinating introduction to the study of fungi is to be found in *The Advance of the Fungi*, by E. C. Large (Cape, 1940) which deals with a number of fungus diseases in an historical way. This can be followed up by *The Plant in Health and Disease*, by W. A. R. Dillon Weston and R. C. Taylor (Crosby Lockwood, 1948) and *Plant Diseases*, by F. C. Bawden (Nelson, 1948). W. A. R. Dillon Weston has written two illustrated booklets which should be useful to farmers and students. They are *Diseases of Cereals*, and *Diseases of Potatoes, Sugar Beet and Legumes* (Longmans, Green, 1949). Hubert Martin's *The Scientific Principles of Plant Protection* (Ed. Arnold, 1942) should be consulted for information about the chemistry of fungicides. *Plant Viruses*, by K. M. Smith (Methuen, 1948) describes present thought about an aspect of plant disease which is becoming increasingly important. The Ministry of Agriculture issue bulletins and leaflets dealing with all the common fungus diseases of farm crops.

Chapter Seven

BREEDING AND FEEDING FARM ANIMALS

Bakewell's work in improving livestock—breeding an art—physiology and breeding of animals—fertility in the male—hormones and development of ova—influence of 'corpus luteum'—condition and fitness for breeding—influence of hormones on milk secretion—oxytocin—practical results—oestrogen and stilboestrol—thyroxine—iodinated proteins—dangers—application of Mendel's work—sex linkage in poultry, 'colour-marking' of calves—genetics—influence of environment upon growing animals—records—milk records—pig recording—artificial insemination—the constituents of food—Pettenkofer's respiration chamber—Kühn and Kellner—the bomb calorimeter—the starch equivalent system—feeding standards—rationing—minerals—control of bulk in feeding.

During the last 200 years farm animals have been greatly improved; how great has been the improvement can best be realized by comparing a photograph of a modern Southdown with an old picture of a sheep of 1700; or a photograph of an Angus heifer with a picture of the beef cattle of two centuries ago.

The improvement of livestock started with the work of Robert Bakewell about 1750. Bakewell had a genius for selecting sires and dams, and once he had discovered a suitable combination he was in the habit of practising 'in-breeding', that is, mating father to daughter or brother to sister, to obtain his desired

result and 'fix the type'. He also made a habit of hiring out sires to his neighbours; he was able to observe the type of animals they got, and if they proved useful he would use the sires again in his own breeding herds. In a relatively few years Bakewell was able to transform the huge, heavily-boned, badly-fleshed, slow maturing animals of his early days into smaller, finer-boned stock of better appearance, quicker maturity, and better quality. Other breeders followed his methods, and soon the best British breeds became superior to any others in the world.

Very little science, in the ordinary sense of the word, went into this remarkable improvement of livestock. The livestock breeder was, and still is, much more of an artist than a scientist. He was able to obtain good results without being able to explain how and why, whereas a scientist not only wishes to get results, but wants the explanation as well. So far, science has not been able to answer all the questions the stockbreeder would like answered.

One of the reasons for this is the comparatively small amount of experimental work carried out in the breeding of farm animals: small, that is, compared with the work done in breeding plants. Farm animals are slow to breed, and often several years must elapse between the mating of a pair of animals and the arrival of the offspring at a sufficiently mature stage to permit of deductions being drawn. Animals, too, unlike farm plants, cannot be self-fertilized, and this leads to complications not experienced in the breeding of many farm plants.

But the researches of the animal physiologist have thrown much light upon some of the problems which beset the breeder of farm animals. The natural curiosity of biologists regarding the structure and mechanism of the animal body has led to the intensive study of every organ, with the result that a great deal more is now known about the functioning of the body as a whole than was the case at the end of the nineteenth century. The reproductive organs have been studied in considerable detail, with some very practical results. It has been discovered, for example, that a male animal is not necessarily fertile because it is potent, i.e. is capable of sexual activity. Although the male may ejaculate fluid during copulation it may be incapable of

fertilizing the female because of the absence of spermatozoa from the ejaculate. It is now a simple matter to determine whether this form of sterility exists in a stud animal. All that is necessary is to examine a drop of the semen under the microscope: in a fertile animal the semen is seen to contain very large numbers of spermatozoa all in active movement, whereas in an animal temporarily or permanently sterile there may be no spermatozoa, or only a relatively few, inactive spermatozoa. The actual vitality of the spermatozoa can also be estimated by the way in which it reacts to sensitive laboratory tests for acidity.

Investigations into the influence which certain hormones exert on the development of ova in the female have also had practical results. The ova, or female reproductive cells, are formed within small sacs called Graafian follicles contained in the ovaries, These sacs come to protrude beyond the surface of the ovary and eventually they burst to release the ova. The development of these sacs or follicles has been shown to depend upon the secretion of a hormone, or growth substance, in a small gland called the pituitary body, situated below the brain: a second hormone, also produced in the pituitary gland, brings about the bursting of the follicle and the release of the ova. It occasionally happens that the ovaries of a cow, for example, remain quiescent, in which case she does not come on heat and cannot be fertilized. It is possible to overcome this condition by injecting into the blood stream an artificially prepared follicle-stimulating hormone. With mares it sometimes happens that the ova are not released from the follicle soon enough after service, with the result that the short-lived spermatozoa perish before fertilization can take place. It is possible to inject the correct hormone into the mare immediately after service, thus ensuring the rupture of the follicle and the release of ova in time to be fertilized whilst the spermatozoa are still active.

When a follicle within the ovary has burst and set free the ova it closes up and becomes changed into a 'yellow-body' or *corpus luteum*. This yellow body secretes into the blood substances which are essential for the attachment and nutrition of the embryo; the yellow body normally lasts for a short period

only if pregnancy does not occur; but while it does exist it inhibits both the ripening of the ovarian follicles and the onset of the heat period. It has been found, however, that it is possible to squeeze out a *corpus luteum* from the ovary of a cow by inserting the hand in the rectum, and if this is done the cow comes on heat within forty-eight hours. The possibilities of this procedure in special cases are considerable. Sometimes both mares and cows are willing to take the male at any time though remaining barren—the complaint is called nymphomania. It has been shown that this condition is associated with the enlargement of several follicles in the ovary and their subsequent degeneration into cysts, whereas in normal ovaries only one follicle at a time develops, subsequently to rupture and discharge the ova. Here, again, it is possible to squeeze out the cysts from the ovary, whereupon the oestrous period begins again.

It has long been known to breeders of farm livestock that the condition of an animal has considerable influence upon its fertility and to some extent scientific investigations have been able to explain why this is so. Excessive fatness in the female, for example, may adversely influence the development of the ovarian follicles, rendering her unable to breed for a whole season. On the other hand, lack of the right kind of nourishment may lead to a poor development of the follicles, with consequent temporary sterility. The observation that the encouragement of regular breeding by female animals leads to continuous fertility can be explained by the fact that postponement of breeding for long periods upsets the cycle of the ripening and rupturing of the Graafian follicles.

Since about 1928 some very remarkable discoveries have been made about the processes which govern the secretion of milk in mammals. The mammary tissue of the female mammal consists of a large number of tiny structures called alveoli, with tubes or ducts forming collecting channels which eventually have an opening in the teat. Each alveolus is made up of a layer of secretory cells surrounding a cavity or collection space. Blood in the vessels which surround the alveoli carries the raw materials to the secretory cells, and the cells pass the milk into the cavity

of the alveolus. All this, of course, was known long ago, but in 1928 some rabbits not in milk were injected with an extract from the pituitary gland, which is situated at the base of the brain, and milk began to form in the alveoli of the rabbits. This was the first demonstration that secretions from the pituitary gland affect the secretion of milk in mammary tissues. Since then it has become known that in the cow the 'letting down' of the milk—that is to say the release of the milk from the alveoli—is brought about primarily by the release into the blood stream of a hormone called oxytocin from the pituitary gland. This leads to a muscular squeezing of the alveoli and ducts, the effects lasting for about seven or eight minutes.

It is known, too, that massage of the udder, or even the preliminary noises or routine associated with milking, can promote the formation of oxytocin and thus encourage the let-down of milk. It is also known that when a cow is frightened another hormone called adrenalin or epinephrin, is poured into the blood, reducing the flow of blood to the udder and interfering with the beneficial working of oxytocin. These discoveries explain why it is important to deal with milking cows in a quiet, gentle manner; why it is necessary to follow a strict routine; why it is better to wash or wipe the udder as soon as possible before milking rather than to wash all the cows before any milking begins; why it is necessary to milk the cow as rapidly as possible (i.e. before the effect of the oxytocin wears off).

Another discovery is that in a high-producing cow the rate of milk secretion in the alveolus slows down as the accumulating milk builds up a pressure within the alveolus. Milk secretion stops when the pressure is about one-quarter of the blood pressure, and later the ingredients of the milk begin to diffuse back into the blood, and this leads to a drying-off process. The need for completely emptying the alveolus, i.e. milking the cows right out, at once becomes clear.

In fact one can say that the very great influence exerted by certain ductless or endocrine glands in all stages of milk production has been one of the most important recent discoveries in animal physiology. It is known that the ovary produces two

secretions, or hormones, concerned with the growth of the udder: one, called oestrogen, controls the development of the duct system, while the other, called progesterone, stimulates the development of the alveoli. The actual secretion of milk depends in the first place upon the secretion from the pituitary gland of a hormone called prolactin, and possibly other hormones as well.

The maintenance of milk secretion, or lactation, appears to depend in part at any rate upon yet another hormone known as thyroxine, secreted by the thyroid gland. Not only have the specific influences of these hormones been experimentally demonstrated both in this country and America, but some of the hormones themselves have been synthesized (or manufactured outside the body of the animal).

Oestrogen, for example, has been synthetically prepared under the name diethylstilboestrol (usually referred to as stilboestrol). When small tablets of stilboestrol and a related synthetic hormone call hexoestrol are inserted under the skin of a well-grown but infertile or maiden heifer, lactation begins in the animal: in some experiments quite fair yields of milk have been obtained, but in others the yield has been small. Individual animals vary very much in their behaviour to this subcutaneous application of stilboestrol, but total lactation yields of up to 700 to 800 gallons of milk have been obtained. It has been suggested by Folley, one of the pioneers in this line of research, that stilboestrol used in this fashion may have a limited application in practice in saving valuable animals which might be slaughtered because of sterility, the sterility possibly being of a temporary nature only.

The effect of feeding the hormone thyroxine to milking cows has been studied since 1934. It was found that cows reaching the end of a lactation gave an increased yield of milk if dried thyroid gland were fed to them, or if thyroxine were injected subcutaneously. In experiments, treated cows gave an average increase of 28 per cent in milk yield, accompanied by an increase of 16 per cent in milk fat. Unfortunately it is not possible to reproduce these striking increases on the farm for various reasons, one of which is the impractibility of giving the necessary injec-

tions: another is that the implantation of hormones is not without its dangers unless carefully controlled. These include the possible onset of nymphomania (see p. 130), the loosening of the pelvic ligaments, and an ugly rise of the base of the tail. But the line of research was continued in a rather different way, utilizing certain information about the behaviour of proteins when combined with iodine. It had been shown in 1914 that these iodinated proteins or iodoproteins could give rise to effects in the animal body similar to those produced by secretions of the thyroid gland: about 1939 it was shown that iodinated casein, when fed by the mouth, gave similar, thyroxine-like results. It was discovered that certain preparations of iodinated casein fed at the rate of 15 grammes daily, increased milk production by 15 per cent: a daily dose of 30 grams gave an increase of 33 per cent. Similar results could be obtained both with cows and heifers in the early and middle stages of declining lactation. These are very remarkable increases which could naturally be expected to attract the attention of commercial milk producers. But this is not the whole story, because there is associated with the increase in milk an increase in the metabolism or rate of operation of the internal bodily processes of the cow. The rate of breathing, the rate of heart beat, the appetite are all increased. The animal loses body weight and the falling off in milk yield in the last stages of lactation is faster than usual. It became obvious that a great deal more had to be learned about the long-term effects of feeding iodinated proteins to cows before their use could be recommended: consequently it was decided that the products should not be made generally available.

The case illustrates how necessary it is that a new scientific discovery shall be looked at from all possible angles in the industry's own interest before being recommended for use in general farming.

When Mendel's principles of heredity were rediscovered, as described in a previous chapter, it was hoped that animal breeding would become a much simpler and more scientific proceeding. Some quite early experiments established the fact that certain characters—such as the presence or absence of horns in

some breeds of cattle and sheep, the colour of the coat in cattle and rabbits, the comb character of poultry—behave as Mendelian units, and are inherited in accordance with Mendelian laws. But the number of characters of economic value so far analysed by breeding experiments is small, because of the cost and the time involved. Numerous analyses have been made of certain characters belonging to small animals such as mice, rats, and rabbits, which breed much faster than cattle, sheep, or pigs, and information is slowly accumulating; but it is not safe to say that because a character in, say, a mouse, is inherited in such and such a way, an apparently similar character in cattle will behave likewise.

One important and economically valuable piece of information has, however, been brought to light as the result of applying the Mendelian hypothesis to the breeding of poultry. It is the phenomenon usually referred to as 'sex-linkage'. The average poultry farmer is not able to tell the sex of a chick at hatching time. The egg farmer is therefore unable to pick out his future laying hens from the cockerels until several weeks have elapsed. This is a serious inconvenience, because he has to feed and house both the cockerels and the pullets until such time as the distinction can be made with certainty. Since the cockerels are of no use to him, food and time spent upon them are wasted. During the last decade or so it has been found possible to distinguish between male and female day-old chicks by a careful study of minute differences in the vent, and expert workers are now able to 'sex' young chicks very rapidly and very accurately. Poultry keepers as a rule do not possess the knowledge and experience which make possible this separation of pullets from cockerels in the day-old condition. Assistance was forthcoming, however, when Punnett at Cambridge discovered, in 1921, that in some breeds of poultry the colour of the plumage is, as it were, linked up with sex. He found, for example, that if a cockerel of a breed having plumage of a buff or golden-brown shade (a 'gold' cockerel) is mated with a hen of a breed with creamy-silver plumage (a 'silver' hen) the cockerels will have silvery plumage and the pullets will have golden plumage. These differences are visible in the plumage of newly hatched chickens; all the silvery-

white chickens can be safely destroyed at once in the knowledge that they are cockerels and worthless for egg production.

Nor is this sex-linked crossing confined to the 'silver' and 'gold' breeds of poultry. A black cockerel matched with a hen having 'barred' plumage, such as the Plymouth Rock, will throw cockerels which are 'barred', and pullets which are black. At hatching, the male chickens can be detected by a whitish patch on the back of the head, because the pullets are completely black. It is important to note that the mating must be made in the manner specified. The distinguishing character is carried by the hen, and is transmitted to her male offspring only. The silver hen transmits the silver plumage to her sons alone. If the cross is made the other way round, and a silver cock is mated with a golden hen, then all the chickens, male and female, are silver. There is in this cross no sex-linkage of plumage colour.

The offspring of a sex-linked cross cannot be used for stock purposes, because the plumage colour is associated with the wrong sex. To overcome this disadvantage Punnett evolved a breed called the Cambar, which is sex-linked within itself. It was derived from a cross between a barred Plymouth Rock and a Gold Campine. The pullets are dark brown, the cockerels pale grey, striped with brown. More recently still he has evolved the Legbar breed (derived from a Brown Leghorn-Barred Rock cross), the Durbar, Buffbar and other auto-sexed breeds. Not all of these are of commercial value.

Use is made of the Mendelian hypothesis in the so-called 'colour-marking' of calves from dairy herds. It is well known that the typical beef breeds in this country cannot provide all the animals needed for meat, and that stores from dairy herds are needed to help make good the deficiency. Owners of milking herds who do not need their own calves for replacements are consequently being urged to use a good beef bull, so that the calves may grow into useful, meaty animals: indeed, some artificial insemination centres offered, free of cost, semen from good beef sires to further this policy. Unfortunately there is always a danger that heifer calves from such crosses may find their way back into dairy herds, there to eat much food and give

little milk. It is possible to lessen this risk by using bulls from certain beef breeds which unmistakably mark their calves. For example, the white face of the Hereford is a dominant factor, and a Hereford bull used on a cow of any dairy breed 'colour-marks' the progeny in such a way that the purchase of the calf as a future dairy cow becomes patently ridiculous. The dominant polled, or hornless, character of an Aberdeen Angus bull together with its black colour, is similarly passed on to all its progeny and should be sufficient to warn off the purchaser of cow replacements.

In the breeding of animals as in plants the scientist has to consider two main things, the genetic constitution of the animal and the environment in which the animal is brought up. By environment is meant such external conditions as geographical situation, altitude, housing, feeding and general management. The genetic constitution, or nature, of an animal is controlled by minute particles of matter called genes, which are found arranged somewhat like beads on a string in the chromosomes as already mentioned on page 47: the chromosomes are found in the cell nucleus. It has been known for many years that the chromosomes play a most important part in heredity, and they have been studied very intensively indeed by scientists in all civilized countries. Each species of animal and plant has its own characteristic number of chromosomes—the human being, for example, has twenty-four pairs: cattle have thirty pairs: house flies twelve pairs, and so on. The chromosomes behave in special ways before and during the fertilization of a female reproductive cell by a male reproductive cell, so that the chromosome number remains constant. It is through the chromosomes that the characters are passed from parents to offspring and that sex is determined. Details of the mechanism can be studied in books dealing with genetics: it is sufficient to state here that genetical studies have made it possible to explain Mendel's arguments, and also to show that the problem of inheritance in both plants and animals is far more complicated than was imagined forty years ago.

It is widely accepted by biologists that the genetical nature of an animal (or plant) is not affected by its surroundings or en-

vironment, using the latter term in its widest sense. In other words the treatment which an animal receives does not modify the essential nature of its chromosomes and the animal does not acquire new characters because of change in environment. But the environment of an animal can influence very greatly the *expression* of a character, and all scientific work with farm animals is emphasizing this point more and more strongly. To give an example. If a bull from a good milking family is mated to a heavily yielding cow, the capacity for milk production will be inherited by the heifers. If managed and fed properly the heifers will grow into cows that yield satisfactory weights of milk. But if the heifers are badly managed and badly fed their capacity for producing milk cannot find expression, and their performance as milkers will be much inferior to that of animals of poorer ancestry, but which have been better managed and provided with plenty of suitable food.

In breeding practice it is often difficult to separate these two things, nature and nurture. It is not always easy to say that an excellent record in, say, milk production or daily live weight increase is due mainly to hereditary qualities or to good management and feeding. Hence the need for care in scrutinizing production records and progeny records. In any constructive breeding policy it is necessary first of all to make sure that breeding animals shall be managed and fed in such a way that the special character under consideration, such as meat or milk production, shall have the fullest chance of showing itself: those animals which respond best to these conditions have then to be selected and used for breeding.

The selection of these animals is not always easy, and in the past it was usually made by a breeder who based his choice upon his experience only, without the support of accurate records. Science is to some extent assisting the breeder by providing measurements of performance: this is especially so in the field of milk production, where one obvious line of approach is through milk records. In the fullest recording schemes the cow's milk is weighed after every milking for the whole of the lactation: in other schemes the milk may be weighed once a week,

Recording provides essential information upon which to select for breeding and at the same time it supplies the farmer with a means of rationing the animal economically. A bull is judged by the milk yields of his daughters compared with the yields of their dams. If the bull is judged by his actual progeny he is called a proven bull or progeny-tested bull: this is a very satisfactory test, of course, but naturally the bull will be of necessity several years old before such records are available, and some breeders object to aged bulls. The other method of evaluating a bull is upon pedigree. There is nothing miraculous about pedigree, it is merely a record of the family tree: if a bull comes from a family having excellent milk ancestry the chances are that he will transmit the milk qualities to his daughters.

What these scientific records do emphasize is that it is quite impossible to judge the milking capacities of either a cow or a bull from appearance alone.

Records are being increasingly used for other things than milk. Measurements of the depth of lean meat and of fat in various joints of cattle and of sheep are providing information about the transference of meat qualities, and in a similar way pig recording is providing information which it is hoped will be of increasing value. Two things are of prime importance in pig raising—namely, the number of piglings that a sow can bring forth and rear, and the amount of meat that the pigs can put on for every pound of food eaten. The pig recording societies aim at providing this information by weighing and counting the litters at weaning, and by weighing and measuring the carcases of the marketable pigs. In this way it is possible to discover those strains which are the most profitable to the farmer, and they can be used for breeding. At the same time the less profitable strains can, and should be discarded; it appears that, in this country, the problem of general improvement in the pig industry is more a matter of eliminating the poor breeding pig than raising the standard of our best breeds. Recording provides the figures upon which the separation into good and not so good can be based.

A development which has already proved useful to many commercial breeders of dairy cattle, and to a less extent of beef

cattle, is artificial insemination, frequently referred to as A.I. Artificial insemination involves the collection of sperm from a sire and its artificial introduction into the breeding passage of the female, where fertilization of the ovum takes place. It is said that a primitive form of A.I. was practised over 600 years ago by the Arabs in breeding horses, but it is only during the last decade that the system has become widely used in this country. Russia and Denmark were the first countries to adopt A.I.; the first association for A.I. in the United States was established in 1938, and the first centre in England was set up in 1942. Artificial insemination has several important advantages for the small dairy farmer, who often cannot afford to buy and maintain a good class bull, and who does not wish to use a co-operatively owned bull because of the risk of introducing disease into the herd. Through artificial insemination the sperm from a single ejaculation can be used to fertilize as many as fifteen or even more cows; a good bull can therefore have its influence spread very widely at a comparatively low cost. Incidentally the bull itself can consequently be proven at an earlier age, and with considerably more evidence in support of his performance because of the increased number of his progeny.

At the A.I. centre are stationed the bulls of the chosen breeds: naturally they are chosen with great care. Semen is collected in an artificial vagina as the bull attempts to cover a cow confined in a special service crate. The semen is at once examined microscopically for abundance and motility of the spermatozoa (see p. 129), and is diluted with three times its volume of a solution of egg-yolk phosphate or egg-yolk citrate at pH 6·7, and is kept in a refrigerator at a temperature of about 40 degrees F. The diluted semen retains its potency for about three days, but degenerates fairly rapidly after that, though an effective life of seven days has been claimed for semen kept by special methods. About 1 ml. (=1 c.c.) of the diluted semen is used to inseminate a cow. It is introduced into the vagina, or even into the uterus, by special methods. The conception rate, i.e. the number of inseminations necessary to bring a cow into calf, is much the same as it is for ordinary matings. Many thousands of calves have been born

from artificial inseminations in Europe, Soviet Russia, and America, and although no scientist pretends that all its problems have been solved, A.I. is undoubtedly well beyond the trial period.

The scientist in the present state of his knowledge may not be able to give the animal breeder as much assistance as he would like but in the feeding of livestock very great advances have been made during recent years as the result of scientific investigations.

Before a scientist can give sound advice to a farmer who wishes to know how to feed his animals efficiently and economically, the scientist himself must know something about the following points: (1) The chemical composition of the feeding stuffs to be used; (2) The digestibility of these foods; (3) The chemical composition of farm animals; (4) The way in which the digested constituents of the food behave after they pass into the blood and are carried to the various parts of the body.

The first point is a comparatively simple one, though, of course, improvements are always being made in analytical methods so that fresh information is continually coming to light. The early analysts soon decided that the four main constituents of animal foodstuffs are: (*a*) Carbohydrates, such as starches and sugars; (*b*) Proteins, which are important largely because of the nitrogen they contain; (*c*) Fats or oils; (*d*) Mineral matter. Modern chemists have not found it necessary to challenge these conclusions; rather they have amplified and strengthened the views of their predecessors. Thus they have proved that the different proteins, fats, and carbohydrates vary in nutritive value, this being especially the case with the proteins. More important still, they have demonstrated that the four classes of ingredients mentioned above, although they form by far the greatest part of the food, may fail to act properly unless the food also contains small quantities of other ingredients, such as the vitamins.

When the bodies of farm animals are analysed it is found that the flesh and muscles consist very largely of protein, together with a certain amount of fat. The amount of carbohydrate is very small, and can usually be neglected so far as feeding prob-

lems are concerned. There is relatively more protein and less fat in a young, growing animal than there is in an older one. The bones are found to contain a large amount of mineral matter, especially calcium and phosphorus.

One of the first problems to confront the worker on animal nutrition was that of finding out how the proteins and fat of the animal are formed from the constituents of the digested food. The early workers had to ask themselves these principal questions: is animal protein formed entirely from vegetable protein? Is animal fat formed entirely from vegetable oils? Or can the carbohydrates and protein also contribute to their manufacture? The first question was not difficult to answer, and one can say with practical certainty that animal protein can only come from protein in the food.

The second question was more difficult to investigate, and the answer was only finally obtained by using a device known as a 'respiration chamber', designed by a German called Pettenkofer. This was a 'box' sufficiently large to accommodate a farm animal, and it had openings through which food could be passed and dung removed. Air was drawn in by means of a fan after it had been measured and analysed. The gases given off by the animal were drawn off into a container, measured, and analysed. By means of this box it was also possible to feed a ration containing a known quantity of nitrogen and carbon, and by subtracting the quantity of carbon dioxide in the air entering the chamber from the quantity in the air leaving the chamber, the amount of carbon dioxide expelled by the animal could be estimated. The amounts of nitrogen and carbon retained in the animal's body could be found by subtracting the amounts of these elements in the dung and urine from the amounts supplied in the food. By simple calculations the weight of protein and fat formed in the body could then be ascertained. As the result of numerous experiments over a number of years it became known that fat could be formed from all three ingredients of a food—protein, fat, and carbohydrate.

The foundations of modern livestock rationing were laid, however, when Gustav Kühn, in Germany, decided in the

1890's to investigate the amount of energy required by bullocks when neither losing nor gaining weight. His work was carried on by Kellner, upon whose work is based much of the existing theory and practice of rationing.

The energy present in a food can be measured by the amount of heat it gives out when completely consumed. The energy in the digested food is utilized by an animal either for the purposes of work or for the production of heat, or is stored up in the body as fat or other tissue. The energy in the undigested part of the food cannot be used by the animal, but it can, of course, be estimated by examining the composition of the dung and of the gases (chiefly marsh gas and carbon dioxide) expelled from the intestines and lungs.

The energy present in food is estimated by an apparatus called a calorimeter. In essentials it is a small closed vessel, usually called a bomb, made of metal, placed inside another vessel containing a known weight of water. The whole apparatus is covered with insulating material to prevent heat escaping. One gramme of the food to be tested, together with enough oxygen to ensure complete combustion, is put in the bomb, and fired by an electric spark. The heat given off during combustion is taken up by the water, the temperature of which is indicated by a thermometer. If the gramme of food thus fired raises the temperature of a gramme of water one degree centigrade, the energy value (i.e. the heat-producing capacity) of the gramme is said to be one calorie. A pound of the same material would have an energy value of 453 calories (1 lb. = 453 grammes). This explanation is necessary, because Kellner used calories when calculating the maintenance and fat production requirements of the animals he had under test.

The first thing Kellner desired to find out was how much food a bullock requires when neither gaining nor losing weight, that is, neither storing up fat or flesh nor losing it. Breathing, feeding, digesting, standing still, are all operations which require energy, and the food necessary to supply these needs is termed the maintenance requirement. Kellner put a 12-cwt. bullock in his respiration chamber and fed it on hay or straw in such amounts that,

so far as could be judged, the animal's weight either remained stationary or showed a slight increase. The calories supplied in the food were known, and the calories in the various excreted substances were determined. The difference between these two totals gave the number of calories required for maintenance. Of course it was impossible to devise a ration so as to get absolutely no change in the bodyweight, but adjustments could be made if, as a result of examining the figures for carbon and nitrogen in the gases, urine, and dung, it was found that small amounts of fat or flesh were being added to, or removed from, the body. Kellner found that a 12-cwt. bullock needs about 15½ lb. of meadow hay (31,000 calories) per day for maintenance, and a 9-cwt. bullock about 14 lb. per day.

Next, the bullock was fed a maintenance ration, but to this was added a definite weight of starch of known digestibility. By calculation, the amount of fat formed in the body by this extra carbohydrate was determined. It was found that for every 4 lb. of digestible starch eaten, over and above a maintenance ration, 1 lb. of fat was stored up in the body.

In a further experiment a known amount of linseed cake was fed in addition to the maintenance ration, but the amount of fat produced by 4 lb. of linseed cake was slightly less than ¾ lb. As a producer of fat, linseed cake is obviously only about three-quarters as efficient as pure, digestible starch. If the value of the starch as a fat producer be put at 100, that for linseed cake is 74. This last figure is called the Starch Equivalent of linseed cake. It means that if 100 lb. of linseed cake are fed to a fattening bullock, *in conjunction with a maintenance ration*, it will lead to the production of as much fat as 74 lb. of digestible starch fed in similar circumstances.

By repeating the experiment with other common feeding stuffs, their starch equivalents were determined. Thus the starch equivalent per 100 lb. of bran is 42, of maize meal 81, of dried sugar beet pulp 65, of oat straw 20, of cabbages 6·6, and so on.

Kellner found, too, that the different constituents of feeding stuffs, fed together in a mixture, behaved as a rule in the same ways as they do when fed separately. Four pounds of starch

plus 4 lb. of linseed cake store up 1¾ lb. of fat. But if there is much fibre present, as in straw and hay, the fat-producing value of the constituents is reduced. This is because the animal has to do more internal work in digesting the fibre, and in searching out, as it were, the digestible from the indigestible material.

Now these experiments were extremely valuable. They showed that fat may be derived from the protein, fat, or carbohydrate in the food—a controversial point since the early days of Liebig's writings. They demonstrated that a definite, calculable amount of food is needed to keep an animal of a definite weight alive at a constant weight. And they showed, above all, that it is possible to predict from an analysis of a food how much fat an animal may be expected to lay on if fed with a definite amount.

To be able to calculate the fat-producing possibilities of a feeding stuff, Kellner conducted further experiments. He made comparisons of the fat-producing values of pure digestible protein, digestible oil, digestible starch, and digestible fibre. He found that 1 lb. of digestible protein is equivalent in fat-producing capacity to 0·94 lb. digestible starch; 1 lb. of the digestible oil of oil cakes is equivalent to 2·4 lb. digestible starch; 1 lb. of digestible oil from cereals and leguminous seeds is equivalent to 2·12 lb.; and 1 lb. of digestible oil from coarse fodders and roots is equivalent to 1·9 lb. digestible starch. In ruminant animals digestible starch and digestible fibre are of the same value for fat production.

To estimate the starch equivalent per 100 lb. of any foodstuff, therefore, it is only necessary to perform the following calculation:

Percentage	digestible	protein × 0·94
,,	,,	oil × (2·4 or 2·1 or 1·9)
,,	,,	fibre
,,	,,	carbohydrate

Sum total = starch equivalent

Nowadays it is necessary to multiply the starch equivalent figure thus obtained by a factor V. This modification has been

found necessary for the following reason: Kellner made use of pure nutrients when he made his experiments, but in ordinary practice the nutrients are not in this condition, and they are intimately mixed up with the indigestible part of the ration. If linseed cake, for example, be fed in the ordinary state it will produce only 97 per cent of the amount of fat theoretically possible. The factor V for linseed cake is therefore $\frac{97}{100}$, and the figure for the starch equivalent obtained by the method just described must be multiplied by 0·97.

Tables are available giving the average percentage composition of all the feeding stuffs likely to be used on the farm. Both the crude and the digestible nutrients are set out, together with the starch equivalent and the value of V. From these figures it is possible to compare the values of different feeding stuffs for the production of growth, fat, work, and so on.

The figures provided in such tables are not of academic interest only. They can, and should, save the farmer money. At the same time, however, it must be remembered that the figures are only approximate. They are the best available, but no one who understands the way in which they have been obtained claims that they are absolutely accurate. They serve as the best available guide, but to work out rations based upon them to two places of decimals is ridiculous.

Kellner's starch equivalent method is now accepted as being one of the best available means of indicating the productive, or energy, value of a feeding stuff. Its great merit is that it gives, by means of a single figure, the information about a foodstuff required by a stock feeder. Before the introduction of starch equivalents it was a very difficult matter to decide what was the practical value of the information provided by a chemical analysis. Kellner's work makes it possible to summarize, in one figure, the information hidden in the analytical data.

It should be mentioned here that Armsby, in America, was investigating the problem of animal nutrition at about the same time as Kellner, and that, on the whole, his results agreed very fairly with those of Kellner's. Armsby used a respiration calorimeter for his experiments. He put the animal in a specially

designed apparatus and measured the heat given off by the animal to find out how much utilizable energy his rations contained.

The starch equivalent method was sponsored in this country by Charles Crowther about 1905. At first its implications and value were not appreciated, but from about 1911 onwards it began to be used more freely, until now it is the basis upon which most of the scientific rationing in the country is based.

Kellner worked with three- or four-year-old bullocks, but it has been found since that his conclusions as to the comparative values of foods apply quite well to the fattening of other full-grown animals such as the sheep and pig, and also to the requirements of the working horse. His conclusions are not so accurate where active growth, or the production of milk and eggs, are concerned. Special tables have been prepared for modifying Kellner's figures for these special purposes, but are not yet in general use.

More recent investigations have shown, too, that the various proteins differ widely in their value for food purposes. The proteins of the cereals are not so valuable as those of the leguminous seeds, for example. The conclusion to be drawn from this is that proteins of several different sorts should be included when a ration is compounded.

It is obviously necessary to have feeding standards of some sort, and these have been drawn up as the result of numerous feeding trials. In this country, for example, it is now fairly well agreed that a 10 cwt. cow needs for daily maintenance alone 6·5 lb. starch equivalent, including ·7 lb. protein equivalent. For each gallon of milk produced another 2·5 lb. starch equivalent including 0·5 to 0·6 lb. protein equivalent are required. In 1925 it was thought that ·6 lb. protein equivalent was necessary for each gallon of milk, but by about 1940 there was enough experimental evidence to justify a reduction to ·5 lb.—a considerable economy in view of the prevailing scarcity of proteins.

In a similar way feeding standards for the maintenance and meat production of cattle, sheep and pigs and other farm livestock have been elaborated.

It is not possible to describe in a book of this sort exactly how

rations for stock are devised, because each class of animal has different requirements: these are set out in some of the books mentioned at the end of this chapter. In devising the ration, three main points require attention. First, the live weight of the animal, for upon this depends the quantity of food necessary for maintenance. Second, the purpose for which the animal is being fed, such as work, fattening, milk production, etc. (the food necessary for this is called the production ration). Third, the capacity of the animal for food consumption; obviously it is no use giving an animal more than it will eat. In deciding upon the actual food to be employed, the points to be looked after are these: the starch equivalent, the amount of digestible protein, the mineral content, and the vitamin content. The importance of minerals in a diet has only recently been rediscovered. Liebig, about the middle of last century, strongly emphasized the need for minerals in animal feeding, but for many years this side of rationing was ignored. Now it is realized that starch equivalent and digestible protein alone do not constitute an ideal food, especially for young animals and milking cows. Both minerals and vitamins, and probably other substances as well, are necessary. It is therefore absurd—and this applies to human nutrition —to look for the solution of nutritional problems in the supply of one particular constituent of the diet. To emphasize the importance of an ample supply of vitamins whilst neglecting the proteins cannot but lead to protein starvation, which is just as disastrous to health as vitamin starvation. Balance in a diet is essential to health and growth: this point is referred to again in Chapter Eight.

The habit of adding a mineral supplement to a scientifically compounded ration is consequently becoming very common. Sodium, calcium, chlorine and phosphorus are the elements most likely to be deficient in the diet of animals fed on plants, and consequently the supplement is often composed of approximately equal parts of salt, sterilized feeding bone flour, and finely ground chalk. Two to three pounds of this mixture are mixed with one hundredweight of the concentrated food.

The new knowledge that has been gained about foods and

feeding during the last thirty years has undoubtedly enabled farmers to ration their animals more efficiently and more cheaply. In the case of fattening animals it has led to a reduction in the use of oil cakes such as linseed and cotton seed cakes. These were formerly fed to the fattening animals in enormous amounts, with two ideas in mind. It was thought that oil and protein formed much fat in the animal and that the undigested food would greatly enrich the manure. Now it is known that protein is a very poor and expensive producer of fat, for only about 30 to 40 per cent of its energy value can be stored as fat, and protein is very dear to buy. It is now known, too, that although cake feeding does increase the manurial value of dung, it does so in a very extravagant manner. It is cheaper to buy extra chemical fertilizers than to try to add the manurial ingredients to the soil through dung by extra rich feeding.

In rationing for milk production there have been considerable developments. Economical rationing in a dairy herd can only be accomplished if the yield of each cow is known, hence rationing is linked up with milk recording (p. 137). The ideas behind the rationing of dairy cows are these: first, to feed a maintenance ration; second, to feed a production ration according to the yield of milk; third, to control the bulk of the ration so as not to overload the stomach and interfere with digestion.

This last point, control of bulk, became very important between the two wars during a time when very concentrated, protein-rich foods could be imported into this country extremely cheaply. So cheap were these concentrates that it scarcely paid the dairy farmer to grow crops to feed to his cows, and even the grassland became neglected. The farmer was able to stuff his high-yielding animals with concentrates to such a degree that small variations in the amount of roughage (hay or roots) easily caused digestive troubles. It became clear that for a 10 cwt. cow under English conditions the total dry matter consumption ought not to exceed about 30 lb., and that bulk must be carefully controlled in animals giving over 5 gallons of milk a day. A 5-galloner might be getting 16 lb. hay plus 17½ lb. concentrates, but in the case of extremely high-yielding cows the amount of

hay fed as a maintenance ration would have to be reduced in order to keep the bulk of the whole ration within the capacity of the cow's stomach. Since 1939, however, the position has altered considerably, and imported concentrates are no longer available in the former quantities. More reliance has to be placed on home-grown foods, which are relatively bulky. It is known that in some countries such as Denmark and Sweden the cows consume far more dry matter than they do in this country, and the question is now being asked whether breeders ought not to breed a type of cow more capable of dealing with bulky foods than many of our present animals.

COLLATERAL READING

The structure and mode of working of the animal body are well described in *The Physiology of Farm Animals*, by F. H. A. Marshall and E. T. Halnan (C.U.P., 1948). The mechanism of animal breeding can be studied in *Farm Animals and their breeding, growth and inheritance*, by John Hammond (Ed. Arnold, 1941): *Animal Breeding*, by A. L. Hagedoorn (Crosby Lockwood, 1939), and *Livestock Improvement*, by J. E. Nichols (Oliver and Boyd, 1948). A survey of the present position of dairy cow breeding is given by E. R. Cochrane in *The Milch Cow in England* (Faber and Faber, 1946): this includes a critical reference to the literature on animal breeding. *The Science of Animal Breeding in Britain: a short history*, by F. H. A. Marshall and John Hammond (Longmans, Green, 1943) will interest those with a taste for the historical development of a subject. *The Artificial Insemination of Cattle*, by John Hammond and others (Heffer, 1947) can be consulted, though this line of work has rather outrun the textbooks.

An easily understood introduction to the study of animal nutrition is given by E. T. Halman and F. H. Garner in *The Principles and Practice of Feeding Farm Animals* (Longmans, Green, 1948) while R. E. Slade and S. J. Watson approach the subject somewhat differently in *The Feeding of Cattle* (Fertilizer and Feeding Stuffs, 1942); see also S. J. Watson's *Feeding of Livestock* (Nelson, 1949). *Rations for Livestock*, by H. E. Woodman (Bulletin 48, Ministry of Agriculture, 1948) is a classic which cannot be ignored by the student: Bulletin 124, *The Composition and Nutritive Value of Feeding Stuffs* (1944) is another valuable handbook.

Information about the various classes of livestock can be obtained from the following books: *The Cattle of Britain*, by Frank H. Garner (Longmans, Green, 1946): *Sheep*, by J. F. H. Thomas (Faber and Faber, 1946): *Sheep Farming*, by Allan Fraser (Crosby Lockwood): *The Production and Marketing of Pigs*, by H. R. Davidson (Longmans, Green, 1948): *Pigs, their Breeding, Feeding and Management*, by V. C. Fishwick (Crosby Lockwood, 1949): *Modern Poultry Keeping*, by Leonard Robinson (Crosby Lockwood, 1948).

Chapter Eight

SCIENCE AND ANIMAL HEALTH

Complexity of modern farming and diseases in animals—tuberculosis—discoveries of Koch—types of tuberculosis—the tuberculin test—'B.C.G.' vaccine—contagious abortion—detection by agglutination test—S.19 vaccine—Malta fever—'Trichomonas foetus' and sterility—foot-and-mouth disease—lamb dysentery—liver rot—life history of the liver fluke—use of carbon tetrachloride and hexachlorethane—round worms—estimating degree of infection—vermifuges—lung worms of pigs—distemper in dogs—lactation tetany—mastitis—'Streptococcus' infection—treatment with sulphonilamide and penicillin—nutritional diseases—pine in sheep—cobalt deficiency—sway-back in lambs and copper deficiency—teart pastures—excess of molybdenum—treatment with copper sulphate—B.W.D. in poultry—detection of carriers—coccidiosis—fowl pox

Scientific investigation and experimentation have done a great deal during recent years to help the farmer to maintain the health of his farm animals. Farming is a much more complicated thing now than it was fifty years ago, and the veterinary surgeon, no less than the medical doctor, finds that this complexity tends to assist the development and spread of complaints which formerly were unknown or considered of little importance; it also accentuates the difficulty of dealing with old-established diseases such as tuberculosis and foot-and-mouth disease.

The crowding together of large numbers of farm animals,

made necessary by certain systems of farming; the unnatural forcing of the females to ever-increasing efforts of production; systems of feeding which reduce the freshness of the food supplied; all these factors increase the possibilities of epidemic disease, whilst modern methods of rapid transport make it possible for diseases to be transferred very quickly from place to place.

It is the veterinary surgeon's job not only to deal with what one may term the ordinary ailments of farm livestock, but also to investigate means of controlling and preventing other nationally important animal diseases like tuberculosis, foot-and-mouth disease, Johne's disease, contagious abortion, liver rot, bacillary white diarrhoea in poultry, distemper in dogs, and so on. The advances made in veterinary science have been so great during the present century that it is possible to refer to a few only of the most important developments.

One disease of animals which is always in the minds of the public as well as of the farmer is Tuberculosis, familiarly referred to as 'T.B.'. Tuberculosis, or scrofula, has always been known, from the very earliest times, as the most prevalent disease suffered by human beings. The importance of tuberculosis in farm and other animals, however, has only been recognized comparatively recently. The characteristic post-mortem symptoms of the disease are the small nodules, or swellings, which later become cheesy in texture. In the public mind tuberculosis is always associated with the lungs, in which case the disease is called 'consumption', or phthisis. But the germ of tuberculosis can attack almost any part of the body—intestines, bones, glands, or skin. The disease need not necessarily cause death, but it seriously impairs the health and activity of its victims.

Modern research into tuberculosis dates from 1882, when Robert Koch proved that, both in animals and in man, the disease is caused by a specific bacterium. It is now customary to speak of three different types of tubercle bacilli, namely, human, bovine, and avian. The first type is the chief cause of tuberculosis in man, particularly of pulmonary consumption. The bovine type causes

practically all the tuberculosis in cattle, whilst the avian type is the sole cause of the disease in poultry. Actually, bacilli of the bovine type can and do infect human beings, particularly the alimentary tract and the bones, whilst pigs are susceptible to tuberculosis of the avian type: cattle are not susceptible to avian tuberculosis, but this form may cause a temporary lesion in cattle leading to reaction to the tuberculin test.

These discoveries are obviously of great significance. They show that the importance of tuberculosis in farm livestock is not confined to the animals themselves, but that it is a matter of national concern. From a more immediately practical standpoint the new information shows how undesirable it is to allow pigs to use pastures frequented by dairy cattle unless the pigs are tuberculin tested. Very recent investigations have shown that the germs of tuberculosis do not survive more than a few weeks when exposed to sun and air on the grass of pastures, so that there is not so much risk of infection being picked up from this source as was formerly supposed.

An animal may be tuberculous and yet manifest no external symptoms for a long time. It is obviously very desirable to be able to detect such an animal by means of a routine test, since the unsuspected case may be infecting its neighbours over a considerable period. The tuberculin test has greatly assisted in the fight against tuberculosis.

It is founded upon the observation that when the bacilli of tuberculosis enter the animal body, the body cells develop 'antibodies,' which attempt to neutralize or destroy the bacilli. If a second infection takes place, or if the products of the metabolism of tuberculosis bacilli given in artificial media are injected into the same animal, a similar reaction takes place. The animal is 'allergic' to tuberculosis. Koch was the first to prepare a substance capable of producing this allergic reaction in tuberculous animals, i.e. he produced the original tuberculin. His tuberculin was prepared by growing tubercle bacilli in cultures of veal broth for several weeks, after which they were boiled, concentrated by evaporation, and filtered. The tuberculin—now called Old Tuberculin or 'O.T.'—was a thick brownish liquid

containing the products of the growth of the bacilli, plus the remains of the veal broth, and glycerin for a preservative. It can be used in various ways.

Old Tuberculin was unsatisfactory in several ways and continued efforts have been made to obtain a tuberculin containing, in particular, less protein of an animal nature. In 1934, Florence Siebert in America prepared a purified protein derivative (P.P.D.) in powder form, from which solutions of tuberculin could be made up with accuracy. Purified protein derivatives of standard potency are now extensively used in this country; a recognized method of use is the single comparative test using both mammalin P.P.D. and avian tuberculin. In this test the tuberculins are injected separately into the skin in clipped areas in the side of the neck: the animal is said to be a reactor if the fold of skin injected with mammalian tuberculin shows markedly more swell- than the fold injected with avian tuberculin. The avian tuberculin is used as a check, since tuberculin is not completely specific to the bovine type of tuberculosis.

The *tuberculin test is not, and cannot* ever be *expected to* be, completely reliable in diagnosing tuberculosis in animals: it is said, however, that it is now 97 per cent accurate.

The investigations conducted during the last half-century have shown that heredity plays only a very small part in spreading tuberculosis. The disease is infectious, transmissible from animal to animal and from animal to man, and can be detected by the proper use of the tuberculin test. The eradication of tuberculosis in farm stock, most important in the case of dairy herds, is consequently a more practical proposition from a scientific point of view than ever before. The limiting factor is the capital cost involved in the destruction of reacting animals. It has been shown in this country, as well as in Sweden, Denmark, and Norway, that a great reduction in tuberculosis can be brought about by destroying infected animals, by separating and isolating reactors to the tuberculin test, which are otherwise apparently healthy, and by feeding calves of these reactors with tubercle-free milk. The carrying out of such a scheme of eradication, though scientifically sound, is in practice complicated and full of

all sorts of difficulties which so far have prevented concerted action throughout the whole of the country.

Numerous attempts have been, and are being made to immunize animals against tuberculosis by means of vaccines. The best method of protective vaccination so far devised appears to be the 'B.C.G.' method, devised by two French workers, Calmette and Guérin. These two scientists obtained a strain of tubercle bacillus from a cow in 1907, and for thirteen successive years cultivated it upon slabs of potato soaked in ox bile and glycerine. At the end of this period it was discovered that the germs, though unchanged in appearance, had become so attenuated, or weakened, that they were unable to infect with tuberculosis a calf into which they were inoculated. Furthermore, it was found that calves treated in this way did not contract the disease when artificially inoculated with germs of ordinary bovine tuberculosis in amounts sufficient to cause severe tuberculosis in untreated animals. Since then numerous trials have shown that, when used in the proper way, Bacillus Calmette Guérin can create a high degree of resistance to tuberculosis. Immunization by vaccines is still in an experimental stage, but since tubercuculosis in farm animals is not a disease that can be cured, the whole trend of scientific thought is in the direction of prevention.

Another very serious disease, especially in dairy herds, is contagious, or epizoötic, abortion, now often referred to as Brucellosis. In this disease the cow 'slips her calf', that is, she aborts, or produces the calf prematurely, usually in a non-living condition. The cow itself usually recovers, unless complications ensue due to the retention of the afterbirth. As its name implies, this disease is liable to spread from one animal to another, so that in a dairy herd a considerable number of cows may in rapid succession slip their claves. This puts the cow-keeper in a very difficult position, because cows will not milk satisfactorily unless they calve down naturally; the expected yield of milk is therefore not forthcoming and the cow-keeper either has to buy cows in milk, or extra milk itself, to fulfil his contract. The loss of the calf is usually of secondary consideration, except perhaps in pedigree herds.

It was not until 1896 that contagious abortion was proved to be caused by a specific bacterium, *Brucella abortus*, though it had been suspected many years previously that such was the case. This new knowledge did not prove very helpful at first, because too little was known about the way in which animals are infected, and because there was no means of finding out if a cow was infected until she actually aborted. All sorts of sanitary measures were recommended, based upon general bacteriological knowledge, such as the washing out of the genital passages of the cow with antiseptics, the disinfection of the cowshed, and so on. Later it was found possible to detect the presence of the germ in an animal by means of the agglutination test (p. 173), and the discovery was made that the disease exists in the majority of herds throughout the country. The bacilli of the disease, however, though they may be present in the joints and lymph glands, only multiply readily if situated in the uterus or in the udder. They are usually spread, not as was at one time thought, by direct introduction into the genital duct, but along with food, water, and occasionally infected milk. They may be spread when an uninfected animal licks an animal which has come in contact with the discharge from an infected cow. The bull may act as a mechanical carrier from one cow to another.

These recent discoveries have made it possible to take fresh steps towards the eradication of contagious abortion. The infected animals can be detected by the agglutination and other tests. The calves of these infected animals may or may not contract the disease; even if they do become infected they may recover before they are a year old, and if they pass the agglutination test they can be taken back to the healthy farm.

Many attempts were made to control the disease by means of vaccines, but until very recently these were not found to be efficient. In the United States during the 1930's intensive research resulted in the production of a vaccine from *Brucella abortus* called 'Strain 19', or S.19, which in 1940 was officially approved in this country for the vaccination of heifer calves. Both in America and in this country the use of S.19 vaccine has had most encouraging results in controlling contagious abortion due to

Br. abortus; statements that the vaccine may give rise to sterility in treated animals have not been backed up by any sound proof. One complication is that the vaccine causes agglutinins to form in the blood, so that a treated animal will react to the agglutination test for a time: this necessitates special precautions where certificates of freedom from contagious abortion of animals exposed at breed societies' sales and shows are required.

The control of contagious abortion is more than a matter for the cow-keepers of the country, because recent research has shown that the causal germ, *Br. abortus,* occasionally occurs in cow's milk as sold to the public. Now *Br. abortus* has been found to resemble very closely the bacillus responsible for Malta fever, or undulant fever, a painful human complaint prevalent in Mediterranean countries, but not unknown here. So far as is known at the moment, it is only particularly susceptible individuals who are likely in this country to develop undulant fever from germs present in cows' milk; but the importance of ridding herds of both tuberculosis and contagious abortion needs no further emphasis.

Another cause of 'sterility' in cattle is the presence in the genital tract of the protozoan parasite called *Trichomonas foetus.* It is only quite recently that this organism has been recognized as one of the causes of abortion, but trichomoniasis is now a quite well-understood condition which can be countered by the withdrawal from use of the suspected bull, and by irrigation or washing out of the uterus of all cows with the appropriate antiseptics.

One of the commonest and most expensive diseases with which the dairy farmer has to contend is an inflammation of the cow's udder called mastitis. In this complaint the milk becomes changed in character and may contain flakes, or clots, or bloodstains, or pus-like matter. The udder may become hard and painful and in extreme cases abscesses may develop. The production of milk falls off as each quarter is 'lost', as the farmer expresses it, i.e. as the quarter of the udder becomes inflamed and incapable of normal milk secretion. The losses caused by mastitis are very great and the disease is undoubtedly one of the most

widespread of bovine ailments. It has been known for quite a long time that some forms of mastitis are due to bacteria, mainly streptococci and staphylococci, but also some other forms. By far the commonest cause of mastitis is *Streptococcus agalactiae*, which enters the udder through the teat canal following contamination from the infected hands of milkers, from infected clothing, machines, bedding and so on. Many attempts have been made to control the disease by injecting into the udder through the teat canals substances which would destroy the bacteria without irritating the udder tissues. Until quite recently, however, consistent successes have not been obtained. The drug sulphonilamide in oily suspensions was then found to give quite good results, and in dry cows particularly the substance called sulphone gave encouraging control. But when penicillin became available in large amounts it was found to be extremely effective in controlling streptococcal mastitis. Two doses of 20,000 units yield about 70 per cent of complete cures; the drug is now supplied in tubes fitted with a nozzle and for the treatment of each quarter of the udder a single tube only is used. All veterinary practitioners are agreed however that the penicillin treatment by itself is not sufficient to control mastitis. The disease is largely one of management and methods, in which correct cowshed routine and hygiene are of supreme importance.

The very important complaint in cloven-hoofed animals called foot-and-mouth disease frequently attracts a great deal of attention from the general public. Foot-and-mouth disease is caused by a virus, which leads to the development of small blisters in the mouth and in the region of the toes of infected animals. It is seldom fatal, but the fever and pain of eating and walking cause such a falling-off in milk yield and such loss of condition generally that its tolerance in this country cannot be considered except as counsel of despair; hence the policy of slaughtering all infected animals and possible contacts, with compensation payable from the public purse. The discovery of the virus-like nature of the cause of the disease dates from 1898, and was due to Loeffler and Frosch; in 1922, Vallée and Carré showed that at least two different viruses may be concerned in an outbreak of foot-and-

mouth disease, called respectively Virus A and Virus O. An attack by one virus does not protect an animal against an attack by the other virus. This fact makes the immunizing of animals by means of vaccines a very much more difficult matter than was formerly supposed. The study of the disease is made very difficult because the virus cannot be cultivated in glass tubes in the manner adopted for bacteria; and although it has recently been shown that guinea pigs can be infected by injecting the virus into the skin, the extraordinarily contagious nature of the disease makes it impossible to study the behaviour of the virus except at a very few well-protected stations. For the time being, therefore, it must be admitted that science has done little to solve the problem of foot-and-mouth disease, beyond suggesting methods of slaughter and disinfection designed to minimize its spread. But for the fact that we are an island, these measures would be of little use, if Continental experiences are a guide.

Some of the most strikingly successful results of recent scientific investigation are to be found in the treatment of certain diseases of sheep. For example, round about 1920 a very serious complaint in young lambs was reported from Scotland and northern England, and later the disease moved south. It attacked young lambs a few hours after birth, causing a rapid scour, and ending in the death of the animals a few hours later. In some flocks the mortality amongst lambs reached 30 per cent. The disease was named 'Lamb Dysentery', and post-mortem examination of infected lambs revealed characteristic yellow spots, about the size of a pin's head, along the small intestine. By 1923, Gaiger and Dalling proved that certain spore-forming bacteria of the anaerobic type are responsible for the disease. (Anaerobic bacteria are so called because they cannot exist in the presence of free oxygen, as in the air, for example; they must have an oxygen-free medium in which to live, though their spores behave differently.) They showed, too, that infection is picked up from the soil through contact, or by sucking the ewe's teats when contaminated with soil, or by contact with dead, infected lambs.

These discoveries led to the preparation of an anti-toxic serum and a vaccine prepared from the causal organism. The ewe can

be vaccinated before the birth of her lamb; the lamb, on sucking milk, soon develops a substance in its blood capable of neutralizing the toxin formed by the parasitic bacteria. Lambs themselves may be inoculated direct with the serum. The immunity conferred by inoculation lasts sufficiently long to carry the lamb over the dangerous first fortnight or three weeks of its existence. The use of this serum has been very successful and thousands of lambs are inoculated every year. Lamb dysentery provides an excellent example of the immediate benefits which veterinary science may confer upon the farming industry.

Another very destructive disease of sheep which is yielding to scientific treatment is liver rot. During the wet years from 1879–81 over three and a half million sheep died in England from this disease, and during the winter of 1920–1 some 60,000 sheep died in the four northern counties of Wales alone. The cause of the disease is a small flat-worm called a 'fluke', which lives in large numbers in the ducts, or tubes, of the sheep's liver. The fluke itself is about an inch long, not dissimilar in shape to a flat-fish, or 'flounder', for which it was at one time mistaken. For a long time it was thought that the fluke had nothing to do with 'rot' in sheep, and all sorts of curious hypotheses were put forward to explain the cause. It was not until 1862 that flukes were definitely proved to be the cause of the disease, and it was another twenty years before the extraordinary life cycle of the parasite first became known. It is worth considering the life history of the liver fluke in some detail, because it illustrates very well how apparently unrelated scientific observations may gradually build up into a discovery of first-rate practical importance.

The fluke in the sheep's liver produces thousands of tiny eggs which pass out with the dung and reach the ground. In suitable conditions the egg hatches into a microscopic larva, capable of swimming in water; the larva perishes if, within about twenty-four hours, it does not find a certain species of freshwater snail. Having found a suitable snail, the larva forces its way in and develops into a bag-like structure, which buds off internally to form half a dozen other creatures. These in their turn bud off

internally to form a dozen or more individuals of small size, resembling tadpoles. These escape from the snail and eventually fasten themselves to blades of grass, when they are called cysts. If eaten by a sheep the cyst develops into a fluke, which finds its way to the liver, where it lives and increases in size.

This life cycle is one of the most extraordinary known to science, and it took one hundred and thirty years to piece together from the scattered observations of scientific men in several different countries. Once the true facts about the life history of the fluke were known, it became possible to explain several things which hitherto had puzzled the farmer. The reason why liver rot is most prevalent in wet seasons is that the necessary water-snails are then most abundant, so that more larvae can survive. Liver rot is uncommon in salt marshes because the snail cannot live in salt water; rot is less common on dry farms than on wet marshy farms because dry conditions are unfavourable to the snails.

Recently a method of disinfecting watercourses and damp grassland has been devised, and the snails can be destroyed, or at any rate reduced in numbers, by the use of a mixture of finely-ground copper sulphate, kainit, and sand. The destruction of the water-snails cuts short the life cycle at the larval stage.

This method of attack, though helpful, is not sufficiently certain to be relied upon absolutely. Some means of dislodging the flukes from the sheep's liver became urgently necessary as soon as the fluke was recognized as the cause of rot. Extracts from the roots of fern proved, until very recently, the most successful of the many substances tried, but they were not entirely satisfactory. About 1925 experiments with carbon tetra-chloride were begun, and in a few years a most successful technique was developed. The drug is administered in capsules of gelatine, and if dosing is carried out at the right time and with suitable precautions—and the operation is an extremely simple one—losses from liver rot can be kept down to a very small figure. Dosing with carbon tetra-chloride, combined with the disinfection of damp places likely to harbour the freshwater snail, have put great confidence into flock masters, who, until the last decade,

felt almost helpless against the ravages of liver rot. More recently still a new drug called hexachlorethane has been successfully used: it appears to be safer, especially for cattle, than carbon tetra-chloride.

The life histories of some other parasitic worms have quite recently been worked out, and again we are confronted with an amazingly complicated series of events. For example, a serious coughing disease of pigs has been known for a long time, and it was discovered that white thread-like worms about two inches in length, resident in the lungs, are responsible. Until about 1929 it was not known with certainty how the worm got into the lungs, with the result that methods of prevention could not be devised very satisfactorily. In 1929 the two Hobmaiers were able to disclose the life cycle of the lung worms as follows. Eggs are produced by the female worm in the lungs, and these hatch at once, the young larvae climbing up the windpipe, or being coughed up, into the mouth, whereupon they are swallowed. They pass out of the body of the pig in the dung and reach the ground. They seem to be incapable of further development unless swallowed by an earthworm. Once in the earthworm they pass through another stage and then remain dormant. A single earthworm may contain hundreds of these partially developed larvae. If the earthworm is swallowed by a pig, a common occurrence as the animal roots about in soil, the larvae are released in the pig's stomach and proceed to bore through the walls of the intestines. After a few days' pause for development into the sexually mature stage, the parasites wander through the tissues of the pig to the region of the heart, where they bore into the blood vessels. Carried along in the blood they eventually reach the lungs, where the irritation they set up leads to coughing, and possibly to pneumonia.

The earthworm seems to be absolutely essential to the completion of the life cycle of the parasitic lung worm; it follows that elimination of infected earthworms is a means of controlling the disease. If young pigs are raised in pens with concrete floors, infection becomes impossible; similarly, if the disease appears in a herd, removal from infected ground to clean pens free from

earthworms will prevent the complaint from spreading. Obviously, too, pig manure should be used for land over which pigs are unlikely to roam.

Perhaps an even more fantastic life history is to be found in the case of certain lung worms of sheep, and parasitic worms of poultry. Here the intermediate stages in development can only take place in the soft tissues of slugs or snails. Hence the recommendation is sometimes made that poultry pens should occasionally be dressed with salt and kainit to destroy slugs.

From what has already been said it is clear that round worms of various types may cause immense losses to stock farmers. It was calculated in 1947 that roundworms parasitic in the alimentary tract of sheep bring about losses through mortality alone of about £350,000 annually—and this takes no account of losses caused by unthriftiness in parasitized sheep. Roundworms—nematode worms—are cylindrical and taper at both ends, and are not segmented as earthworms are. The species known as *Haemonchus contortus*, which lives in the fourth stomach of the sheep, is about an inch long in the female and only half as long in the male. It is a most expensive parasite and has been the subject of much study in recent years. The female, it is now known, may lay from 5,000 to 10,000 eggs which pass out in the droppings of the sheep. From the eggs emerges a larva, or immature worm, which lives upon bacteria in the droppings until it moults its skin: the second larva, as it is now called, also feeds, but when it is ready to moult it remains encased in the moulted skin of the second larva and is therefore unable to feed. This third larva is called the infective larva, because it, and it alone, can withstand the action of the digestive juices of a sheep and develop (after several further moults) into a sexually mature adult worm. It takes a minimum of three days for newly hatched larvae to develop into the infective phase, and this knowledge is of some use in reducing the spread of the parasite by controlled grazing. Recent work has shown, too, that the infective larvae climb up and down the foliage of pasture plants quite readily. They are found in greatest numbers in plants at dawn and dusk, for they dislike intense light and prefer moist conditions: the

bringing in of animals at night—where such a thing is possible—is therefore likely to reduce infection. It is known, too, that clovers are likely to harbour more infective larvae than some grasses, and consequently an 'improved' pasture may be more dangerous from this particular aspect than a grassy pasture containing little clover.

Methods of obtaining an idea of the degree of infestation of farm animals by roundworms have been devised. In one method the contents of each part of the alimentary canal are washed out into large jars: the fluid is made up to a known volume and immediately after stirring a definite quantity, say 40 or 50 c.c., is removed and examined for roundworms. By calculation the number present in that part of the intestines under examination can be determined. Another method is to estimate the number of nematode eggs in the droppings of the animal. This may be done by a dilution method as just described, or by a flotation method in which the number of eggs in a tiny quantity of droppings is estimated by means of a microscope as they rise to the surface of a strong solution of common salt. According to Lapage, if sheep are passing out more than 2,000 eggs per gramme of fæces daily, it will usually mean that they require treatment for infestation with nematodes present in the alimenmentary canal. In the case of horses and cattle, fewer eggs per gramme will usually indicate the presence of numbers of adult roundworms sufficient to cause disease.

It is now widely realized that the mere presence of parasitic worms in the intestinal canal does not necessarily indicate a state of 'disease' in the host. In the healthy farm animal there is a state of equilibrium between host and parasite. Only when this equilibrium is upset, as by poor feeding of the animal or exposure to cold or excessive intake of larvae, do symptoms of 'disease' become apparent. Nevertheless it is frequently desirable to reduce the numbers of roundworms in the intestines of animals, particularly sheep. Two of the most modern drugs used as vermifuges are phenothiazine and a mixture of copper sulphate and nicotine. Tetrachlorethane, already mentioned when discussing the liver fluke, is also being used.

Although distemper in dogs is of little direct importance in in farming, a brief reference to this complaint may be made on account of the great public interest in dogs of all kinds. Distemper is an extremely infectious disease, especially of young dogs, which in the past has been the despair of dog lovers who have felt quite helpless in the face of an outbreak. The infected animals either recovered or succumbed—that was all that could be said about it. In 1905 Carré showed that distemper is caused by an ultra-microscopic virus, but another twenty years elapsed before the whole matter was properly thrashed out and a satisfactory means of combating the virus could be devised. Laidlaw and Dunkin were able to infect ferrets with dog distemper, and for various reasons this simplified their investigations. Ferrets are much more susceptible than dogs to fatal attacks of distemper, and by using ferrets these two workers were able about 1926 to devise an anti-virus vaccine against distemper in dogs. Actually, anti-distemper treatment involves first of all the use of vaccine, followed a week later by a small dose of living virus to ensure immunity. As a result of these investigations, distemper has lost much of its terror, and can now be regarded as a preventible disease.

Recent investigations into the composition of the blood of animals, carried out by Green and Dryérre in this country, have had most spectacular success in the treatment of a non-parasitic disease called Lactation Tetany. This complaint chiefly affects cows during the spring months. It occurs very suddenly indeed, the symptoms are alarming, and death in convulsions follows an hour later. One can imagine the distress of a farmer if his animals succumb to a mysterious illness before even he veterinary surgeon can arrive. Until recently very little could be done for animals attacked by this little-known disease. Green and Dryérre then discovered that the blood of smitten animals is very deficient in the element magnesium compared with the blood of healthy animals. Magnesium deficiency in the blood was found experimentally to cause severe nervous disorders culminating in spasms and convulsions; conversely, it was discovered that injections of soluble magnesium salts into a vein or under the skin

temporarily raises the magnesium content of the blood sufficiently high to overcome the nervous irritability, giving the animal a chance to recover. The present-day treatment for lactation tetany is therefore the injection of a small quantity of magnesium borogluconate into a vein or under the skin by means of a hypodermic syringe. What actually causes the reduction of magnesium in the blood is not fully understood.

During the last twenty years poultry keeping, both on specialized and on mixed farms, has undergone great developments, and there has been a correspondingly great increase in the attention devoted to poultry diseases. The rise of mass production methods in poultry rearing, and the use of battery layers whereby the birds are housed tier upon tier in miniature skyscrapers, have made it possible to keep enormous numbers of poultry on a very small area of ground. Concentration of livestock in this manner makes the diagnosis and treatment of diseases very important indeed, not only on account of the capital involved, but also because diseases can spread very rapidly in such circumstances.

One of the most destructive poultry diseases is that known as Bacillary White Diarrhoea, usually shortened to B.W.D. This is a disease which chiefly attacks young chicks shortly after hatching, and it has in the past caused tremendous losses. The chicks appear stupid and lethargic, and there is a whitish discharge from the vent. They may die off very rapidly. It has been known since 1908 that the cause of the disease is a bacterium called *Salmonella pullorum*, but not until comparatively recently was it proved that infection comes mainly from the egg itself. In other words, the bacillus is already in the egg at the time of laying. Not all the chicks which contract the disease die; some survive, and the germs remain within their bodies as they develop into pullets and adult hens. When these carriers lay eggs, the bacteria enter some of the embryo chicks, which from that moment are doomed to contract B.W.D. Infection is spread very rapidly by the excreta of affected birds in the confined space of the incubator and the brooder.

The discovery that adult birds may carry the disease in this

way, without showing any external symptoms of infection, is a most important one, particularly as no successful treatment of diseased chicks is known. Prevention is obviously the best method of controlling bacillary white diarrhoea, and it is fortunately possible to detect the carriers by means of an agglutination test. In the early form of test about forty drops of blood were taken from a vein under the wing and put into small tubes for testing in a laboratory.

The technique was rather laborious and involved not only a lot of clerical work but also long delays. Although the tube method is still used it has been to a large extent superseded by the 'whole blood rapid plate' agglutination test, which is very reliable and which can be conducted entirely on the farm with immediate results. The equipment consists of a porcelain plate: a holder with a pricking needle at one end and a wire loop of standard size at the other; some antigen (which is a suspension of B.W.D. organisms) tinted with crystal violet for ease in reading, in a bottle constructed so as to deliver a standard drop. A standard drop of antigen is placed on the plate: a vein under the wing of the bird is pricked, and a loopful of blood is mixed with the antigen. In two to three minutes a positive reaction is shown by the formation of clumps of a darker violet colour in a lighter liquid.

A pullet which reacts to the test should not be used for breeding purposes. It is the custom nowadays to buy breeding stock, day-old chicks, and eggs for incubation only if they are guaranteed to derive from stock which have passed the B.W.D. agglutination test. Naturally, other preventive sanitary measures are desirable, such as the removal of excreta and diseased chicks, and the disinfection of chick incubators.

Another extremely costly disease of poultry is Coccidiosis, which is caused by a microscopic, single-celled creature called a coccidium. Research carried out during the last quarter of a century has revealed the enormous capacity for multiplication possessed by coccidia, which explains to some extent the widespread nature of the disease. Coccidia are picked up by birds and develop in the lining of the intestinal walls. A single coccidium

may give rise to one and a half million descendants, and the inflammation set up in the intestines leads to the death of many of the infected birds. Many of the coccidia pass out with the excreta, and so are liable to be picked up by the other birds using the same pen. The recognition of the fact that infection is spread chiefly through the droppings has led to the practice of rearing chickens on wire-netting floors; the droppings fall through beyond the reach of the chicks as they take their exercise. If coccidiosis is suspected a considerable control can be achieved by the immediate use of one ounce of sulphamezathine in every six gallons of drinking water, combined with the disinfection of all utensils, etc., with a solution of one part of liquid ammonia in nine parts of water, ~~to destroy the coccidia~~.

Work carried out during the last twelve years has destroyed many illusions about yet another poultry disease, namely fowl pox or roup. In this complaint the skin becomes covered with pox-like lesions; they are found in the mouth, on the comb, and round the eyes. Usually adult birds only are affected, with loss of condition and egg-laying power. Hitherto the disease has been considered extremely infectious, but Doyle and Minett have shown that it is spread by contact and that a virus is responsible. These two workers made the interesting discovery that it is very difficult to infect pigeons with virus of fowl pox, whilst pigeon pox is easily transmissible to fowls. They argued from this that it might be possible to protect fowls by vaccinating them with mild doses of pigeon pox, in much the same way as cow pox is used to immunize human beings against small pox. Since 1930 such a vaccine has been available, and its use has enabled poultry keepers to control fowl pox so effectively that the disease is now seldom seen.

Ill health in animals may be due to other causes than specific parasites and bacteria. It may be nutritional—that is, the diet of the animal may be lacking in one or more elements essential to well-being. Modern systems of farming make greater demands upon livestock than the more leisurely systems of fifty years ago: there is a demand for earlier maturity in the animals themselves coupled with more intensive rearing and feeding methods. It is

therefore not surprising that nutritional, and especially deficiency, disorders should be more common now than they were half a century ago. At the same time farm livestock come under much more searching and scientific observation now than formerly, and improved methods for the examination of soils and fodder make it more easy to recognize the deficiencies, so that the apparent increase in these troubles may not be entirely real. Among the 'trace' elements which have been most thoroughly examined in connection with animal ill health of recent years are cobalt, copper and molybdenum.

In certain parts of these islands, notably in Devon and Cornwall, North Wales and Scotland a complaint among sheep known as 'pine' has been recognized for very many years. The sheep do not thrive, there is a general lassitude, with dull, half-closed eyes, poor or dropping wool, and setting back of the ears. In Scotland it had been realized that certain farms and even certain fields were very subject to this pining disease, and the practice had grown up of moving sheep to sound land when pining made its appearance.

Only during the last fifteen years has the true cause of pining been discovered, and it came about as the result of researches carried out in the Antipodes. In Australia and New Zealand there exist diseases of sheep (and cattle) similar to pine, called enzoötic marasmus and bush sickness, which at times have been so severe that whole farms have been abandoned. It was found that these complaints could be alleviated by the administration of certain soluble iron salts, and it was argued from this that a deficiency of iron in the soil is the cause of pine. In New Zealand, experiments were begun with limonite, containing hydrated oxide of iron, to apply iron to the soil. But it was soon found that different samples of this ore had different effects which were not correlated with the content of iron. In Australia similar results were obtained, and it was then proved that iron was not the curative element at all, but that impurities in the limonite were responsible for the alleviation of the disease. Eventually, after much research by numerous workers in New Zealand and Australia, it was proved beyond doubt that a lack

of the element cobalt was responsible for at least some types of wasting disease in sheep; after this progress was rapid.

Extremely small amounts of cobalt are needed to prevent pine, something in the region of 1 milligram per head per day. These small quantities can be administered as a drench, as a mineral supplement added to other food, or as cobalt salts combined with fertilizers used to top-dress pasture. All these methods have been successfully employed, and although it cannot be claimed that there is nothing more to learn about pining disease in sheep, yet the grazier in affected districts now has at his command a means of alleviating what used to be regarded as an incurable wasting disease.

A deficiency in copper appears to be the cause of the disease in lambs called 'sway back'. In this complaint there is a curious staggering gait, and the white matter of the brain and spinal cord suffers a partial breakdown. The lamb is affected before it is born, and the method of controlling the disease is to feed or dose the pregnant ewe with small quantities of copper sulphate. A fortnightly dose of 0·5 grammes of copper sulphate has been found successful in many cases: copper 'licks' have also proved useful. There is pretty general agreement among those who have studied the complaint that swayback is not entirely due to a deficiency of copper, but that there may be a complication due to other factors. It has been suggested that the reported increase in cases of swayback is associated with the increase in popularity of the new drug phenothiazine which is ousting the copper-nicotine sulphate drench in the treatment of sheep for worms: if this is so, it provides an interesting example of how new problems can arise from the solution, or partial solution, of what may appear to be some totally unrelated problem.

Ill health in animals may be caused not only by a deficiency of a particular element in the diet but also by an excess of an element. An outstanding, if local, example of the latter is provided on the so-called 'teart' pastures of Somerset, Warwickshire and Gloucestershire. In Somerset alone there are some 20,000 acres of land which when in grass are liable to cause serious intestinal scouring in cattle, particularly milking cows

and young stock. The trouble has been known for very many years, and it is so serious in some places that the pastures cannot be grazed and have to be cut for hay. Many investigations of the teart pastures were made in the early part of this century, particularly with reference to the possible presence of injurious herbs, but apart from the observation that all the teart land is situated on soils derived from the Lower Lias formation, little was discovered. In 1936 Ferguson, Lewis and Watson began the spectrographic examination of teart soil and foliage, and observed that small amounts of the element molybdenum were present, the quantity being about ·002 to ·01 per cent in the foliage. The degree of teartness varied roughly with the molybdenum content, and the molybdenum varied with the season, being highest in autumn. Direct feeding trials were then instituted, and it was found that animals drenched with, or fed, quite small amounts of sodium molybdate suffered the same sort of scouring as animals grazing teart pastures. Grassland on which sodium molybdate was sprayed also caused scouring. It became clear that the cause of teartness is an excessive, though relatively small, amount of molybdenum in the herbage. The next step was to find a prevention or a cure for teartness. It so happened that in 1938 there appeared a report on an investigation into a case of scouring on one of the Dutch polders, in which it was suggested that a deficiency of copper might be a cause. Following this up, direct experiments were made by drenching cows with sodium molybdate until they scoured: then they were drenched on alternate days with copper sulphate and with sodium molybdate. The copper sulphate stopped the scouring. In this and other ways it was discovercd that a daily dose of 2 grammes of copper sulphate fed to cows on teart pasture prevents scour and loss of condition: the chemical can be fed quite easily mixed in the concentrate ration, and seems to have no harmful effect upon the animals.

During the investigation it was observed that clovers take up much more molybdenum from the soil than grasses, and that Yorkshire Fog grass absorbs far more than other grasses. These facts explain why it is that 'improved' teart pastures always cause

worse scouring than inferior pastures, for improvement is due to the elimination of inferior grasses like *Agrostis* and to the encouragement of clovers, particularly white clover. They also explain why the use of basic slag increases teartness, for slag encourages wild white clover (see p. 80). The investigation is interesting, too, in showing how complicated the interactions of mineral elements may be. If the value of copper sulphate in controlling scour had been discovered before the molybdenum effect had been demonstrated, it might well have been concluded that teart is due to a deficiency of copper instead of an excess of molybdenum. Exactly how the copper sulphate operates is not properly understood.

COLLATERAL READING

A useful recent book written in non-technical language is *Good and Healthy Animals*, by J. D. Paterson (E.U.P., 1947), and this can be supplemented by the summaries of recent work in veterinary work published annually in the Journal of the Royal Agricultural Society. Reference works of a general character are *The Practice of Veterinary Medicine*, by D. H. Udall (New York, 1947) and *Black's Veterinary Dictionary*, by W. C. Miller (A. and C. Black). The Ministry of Agriculture publishes at intervals leaflets and bulletins dealing with important matters of animal health. Consult also *The Veterinary Record*, published weekly.

Chapter Nine

MORE APPLIED BIOLOGY

Bacteria and other microscopic organisms—the agglutination test—soil organisms—decay—the nitrogen of farm manure—synthetic farm manure—the problem of surplus straw—compost—free nitrogen—the special value of leguminous plants—inoculation of lucerne seed—bacteria and the handling of milk—influence upon methods of milking—the milking stool—sterilization by steam and hypochlorites—keeping quality of milk—importance of cooling—pasteurization—starters—estimation of bacteria in milk—plate test—dye reduction tests—resazurin and methylene blue tests—National Milk Testing and Advisory Scheme—ensilage—lactic acid and the use of molasses—mineral acid or A.I.V. method—pit silos—ensiling kale—control of weeds in cereal crops—sulphuric acid—DNOC—plant growth substances or hormones—early experiments—development of MCPA and DCPA—fruit development by hormones—prevention of pre-harvest drop in apples—prevention of sprout formation in potato tubers—earthworms—use of statistics in field experiments.

In this chapter some account is given of the ways in which other forms of biological research are assisting the farmer. In particular, the work of the bacteriologist is considered at some length, but reference is also made to recent work on weed control, ensilage, compost and so on.

The work of the bacteriologist influences agriculture in many different ways. It is essential to the proper understanding of certain problems in soil fertility, in diseases of plants and animals,

in the handling of milk, and so on; and whilst it would have been possible to deal with bacteriological work by spreading it over several of the preceding chapters, it has been thought preferable to devote a section specially to this branch of scientific investigation.

The term 'micro-biologist' would be more accurate than 'bacteriologist', for it has a wider meaning. A bacteriologist pure and simple deals entirely with bacteria, which form a distinct group of very small, very simple, plants called the Schizomycetes. The micro-biologist, however, is concerned with all the numerous tiny forms of life which may be found in the soil, and in plant and animal tissues. He has to deal not only with the true bacteria, but also with closely related forms of plants such as algae and fungi, and with lowly forms of animal life such as the protozoa. These very primitive animals may have a profound influence upon the bacteria in a soil, and they may also cause diseases in farm animals and poultry.

Some mention has already been made (Chapter Six) of the bacterial diseases of plants; some of the more important diseases of animals caused by bacteria and protozoa receive attention in Chapter Eight. The present discussion is chiefly confined to the effect of micro-organisms upon soil fertility and the handling of milk.

Some account must, however, be given of the agglutination test, to which reference has several times been made in Chapter Eight. The agglutination test is a most useful one in diagnosing the presence of disease germs in living animals exhibiting no external symptoms of disease. The test depends upon the fact that the blood serum, that is the watery portion of the blood, of infected animals develops substances called agglutinins, which cause the disease bacteria to clump together and sink to the bottom of the vessel containing them. The test is carried out by taking a sample of blood from the subject under examination: assume that contagious abortion is suspected. After the blood has clotted, some of the serum on top is mixed with a suspension of *Br. abortus*, the bacterial cause of the disease, and the tubes are incubated at body temperature for eighteen to thirty-six

hours. No change occurs if the animal is free from the germs of contagious abortion. If the animal is a carrier of the germs there is a progressive flocculation, or clumping together, of the suspected bacteria, which sink to the bottom, leaving a clear liquid above. The agglutination test is not infallible, but it has undoubtedly been extremely useful in the diagnosis of germ carriers.

The soil, of course, teems with micro-organisms. Every gramme of rich soil contains millions of bacteria and protozoa. Many of them are responsible for decay or putrefaction, whilst others play a most important part in supplying nitrogen to farm crops. Some may be dangerous to animals, such as the bacilli causing anthrax and tetanus.

Soil bacteriology, to use the more familiar term, is of recent growth, for it must be remembered that the nature of bacteria was unknown until Pasteur, about the middle of last century, laid the foundations of the science. When more and more became known about these lowly organisms it was realized that they are of great importance in farming. In the first place, it became obvious that bacteria, with various fungi as well, bring about decay. Decay is essential to the continuance of life. During decay, the bodies of animals and plants are resolved into their constituent elements, which return either to the soil or to the air, to be used again by other living organisms. Without decay a farm would become cluttered up with dead plant and animal remains, and life would sooner or later become impossible.

The farmer has a special interest in what happens to the nitrogen of decaying material. In a manure heap, for example, bacterial changes may lead to a loss or a profit on the crop to which the manure is applied. Most of the nitrogen fed to an animal is returned to the manure in the urine. If bacteria get to work upon the urine-soaked straw much of the nitrogen may vanish into the air as ammonia.

Bacteriologists found that the bacteria which set free the combined nitrogen in the manure require a lot of air. They proved that if a manure heap can be trodden down very tight so

as to exclude air, the loss of nitrogen during storage can be cut down to a minimum. That is why one often sees farm carts being drawn right over a manure heap before being unloaded. The trampling drives out the air. This discovery alone must have saved farmers many thousands of pounds during the fifty odd years that the compaction of manure heaps has been practised. A smell of ammonia coming from a loosely made heap of manure is a sign of harmful bacterial activity, which causes much of the cash value of the manure to escape.

Farmyard manure is becoming increasingly difficult to obtain, yet the strawy organic matter is known to be of great importance in maintaining fertility. Humus is essential for good crop growth and the retention of soil moisture. Scientists asked themselves if it would not be possible to make an artificial farmyard manure quickly and efficiently. To this end a careful study was made of the organisms known to be intimately concerned in decay, and in 1921 Hutchinson and Richards discovered a means of synthesizing organic manure. They found that the putrefactive organisms work very rapidly if they are supplied with plenty of soluble nitrogenous material, are kept moist, and are given some basic substance such as lime to neutralize the acids they manufacture. In these circumstances the organisms will break down green vegetable matter in a few weeks to a substance very similar in appearance and chemical composition to farmyard manure. The nitrogen is usually given in the form of sulphate of ammonia. Modifications of the process are used on farms on the Continent where there is little or no livestock to trample the straw. Calcium cyanamide alone has recently been used for a similar purpose. It is also employed to assist the rapid rotting of a green crop ploughed directly into the soil. The crop—mustard, vetches, rye, etc.—is flattened out with a roller and four hundredweights of calcium cyanamide per acre are broadcast. A few days later the green stuff is ploughed under and tremendous bacterial activity ensues, leading to the enrichment of the soil with both organic matter and nitrogen. It is said, also, that the rate of decay is such that the underground stems of the weed called couch-grass, or squitch, are destroyed during the process.

The increased acreage under cereal crops brought about during the 1939 war led to the accumulation of straw on many farms for which no satisfactory use could be found. It was not possible to tread it into manure because there was not sufficient stock in yards, and it was often very difficult to plough in straw after the combine harvester (see p. 205). Much of the straw was consequently burned. Repeated attempts were made to compost the straw, using sulphate of ammonia as the source of added nitrogen, and lime to prevent acid conditions developing. Unfortunately, for the composting system to work well very large volumes of water are needed to moisten the straw properly, and it was found that about 800 gallons of water are required per ton of straw. Such large amounts of water are not available on many farms, and they are in any case expensive to pump: these deficiencies, in conjunction with the labour needed to build the heaps, has acted as a brake upon straw composting.

It was also found out in the early days of the food production drive that where raw straw is ploughed into the ground after the harvesting of a cereal, the yield of the following crop may be seriously affected. This appeared to many farmers to be quite ridiculous, seeing that straw is one of the raw materials for making humus. But there is really no mystery about the business, and the explanation follows logically from the original work of Hutchinson and Richards and other workers (see p. 33). It is that when the putrefactive or decay organisms in the soil get to work upon the ploughed-in straw they need a lot of nitrogen, and this they obtain from the organic nitrogen in the soil. The result is that during the preliminary stages of rotting of straw the available soil nitrogen is diminished, and a crop growing on top of ploughed-in straw may suffer considerably from nitrogen starvation. Later, of course, when the rotting process has been completed, the combined nitrogen becomes available to the plant. In practice the temporary shortage of nitrogen in the soil can be overcome, and the actual rotting can be encouraged, by scattering sulphate of ammonia on the straw either before or after ploughing, at the rate of 1 cwt. sulphate of ammonia to every ton per acre of straw—which usually means between 1 to 2 cwt.

of the fertilizer per acre. This is now a routine operation with those farmers who combine harvest their corn and who have insufficient stock to warrant baling the straw for use in the buildings during winter.

When a compost heap is properly made there is a considerable rise in temperature, up to 60 or 70 degrees C. in the centre of the heap, and this is probably sufficient to destroy the vitality of weed seeds present in the material. At first the decomposition is carried out mainly by aerobic, or air-requiring, organisms, but the later stages are continued by anaerobic forms. During the decomposition there are considerable losses in organic matter and nitrogen, and the availability to plants of the nitrogen in the compost is low. Certain warm advocates of compost claim almost mystical powers for composts made according to special formulae and these claims conflict with the evidence obtained from controlled scientific experiments. The latter indicate that the value of a compost as a fertilizer (neglecting its effect upon soil structure) is no greater than that of the ingredients used in its preparation. Further, for some crops, composts used at average rates do not provide nitrogen for optimum growth. On the other hand it is very difficult, if not impossible, to measure quality and flavour by existing scientific methods, and there is a considerable body of opinion that the use of composts does improve both these. It is quite clear that a great deal more carefully obtained evidence about the virtues and behaviour of composts is needed.

Investigations into the habits of soil organisms have shown, too, that the stirring of a soil during summer actually causes an increase of soil nitrogen. Certain bacteria living in the upper layers extract nitrogen from the air to build up their tissues, and when they die the nitrogen becomes available to any crop growing there. The amount of nitrogen thus added to the soil may be worth several shillings an acre. The process only goes on in a non-acid soil, and this is another reason why liming is so essential on many farms. This extraction of nitrogen from the air is very unusual, because most green plants are not able to utilize the tremendous stores of nitrogen in the air around them.

It is just over sixty years ago that the discovery was made of the reason why leguminous plants like clover and beans and lucerne are so rich in nitrogen, and why they leave the soil richer in this element than they find it. Two Germans, Hellriegel and Willfarth, proved that nitrogen-assimilating bacteria live in the nodules, or warts, so characteristic of the roots of leguminous plants. The bacteria steal a certain amount of food from the roots, and combine this with the nitrogen they take from the air. The nodules consequently become very rich in nitrogen; some of this nitrogen is used by the plant when forming its own seed. Some of the nitrogen escapes into the soil, and this, together with the other nitrogen set free during the decay of the nodules, adds considerably to the fertility of the soil.

This discovery has a special value, on account of the interest being taken in lucerne or alfalfa crops. No leguminous crop will grow really successfully unless the root nodules develop and the partnership between plant and bacteria is set going. Each plant has its own special form of root nodule bacteria, which alone will infect its roots. In our English soils there is usually a sufficiency of these organisms to infect all our crop plants. Lucerne is a foreign plant, however, and the required bacteria are not to be found here. Consequently the bacteria must be added to the soil before the crop will grow properly. This is done by 'inoculating' the seed with a culture of the required organisms. A culture is merely a narrow glass tube containing a jelly, upon the surface of which are growing countless numbers of nodule bacteria. The seeds are moistened with skim milk or other substance to make the germs adhere to them, and the jelly is shaken up, scattered over and well mixed in with the seed. The seed is allowed to dry in darkness and then sown as soon as possible.

An important discovery was made a few years ago to the effect that all types of lucerne root nodule bacteria are not equally effective. The best strains were selected and cultivated. These improved strains are now available to the farmer at a low price. It costs about 4s. to treat enough seed to sow one acre, and very little lucerne is now sown without this preliminary inoculation. Inoculation can also be effected by scattering over the seed some

air-dry soil from a field in which lucerne is known to grow successfully; it is preferable to use a special culture because of the greater virulence of the cultivated bacteria.

During recent years a very great deal of research has been carried out upon the relationships of bacteria with milk and milk products. This work has revolutionized the production and handling of milk, and affects all consumers of the product. The real starting-point was the proof of the fact that a healthy cow produces milk which is free from bacteria. Milk is a substance secreted from groups of cells which form most of the tissues of the udder. These cells are amply supplied with blood from the milk 'veins', and they discharge milk which collects in the ducts of the udder and in the milk cistern just above the teats. The teat is closed by a muscular ring, and if a sterile tube is inserted and some of the milk drawn off and examined, the milk is found to be sterile: no bacteria are present.

This is very significant, for it means that any germs in the milk as it reaches the consumer must have got in from outside sources. Of course an unhealthy cow may infect her milk, but the number of such cows is relatively very small because of modern methods of inspection and management. The problem of serving the public with pure milk is consequently very largely a matter of paying special attention to methods of milking and handling.

Bacteria are almost everywhere. They are present in the air of cowsheds, on the hair of the cows, in the breath of man and beast; they can live in unclean utensils, they are carried on the feet of flies, and so on. A better realization of the possibilities of bacterial contamination has led to the adoption of improved methods of milking. Hair on the hindquarters and udders of cows is now clipped short. When this was first proposed objections were raised that it would adversely affect the health of the cows by giving them chills, but experience soon showed that this did not happen. The same objection was made when it was proposed to wash the flanks and udders of cows immediately before milking. Clipping, grooming and washing very greatly reduce the possibility of bacteria entering the milk in the cowshed, and the use of milk-pails with a domed or covered top in

place of the enormously wide top of the ordinary bucket is a still further safeguard.

As an indication of what scientific inquiry may do in improving methods, one may quote the example of the milking-stool. Until quite recently this piece of equipment was regarded as nothing more than a necessity, and when not in actual use was allowed to kick about the cowshed or dairy in varying degrees of neglect and dirt. When the problem of clean milking methods was being seriously investigated it was realized that the milking-stool is a very possible source of contamination, as it is the last thing touched by a milker before he begins to milk. This has led to the treatment of the milking-stool as part of the equipment requiring special cleaning and sterilization, and the wooden article is giving way to stools made of more hygienic metal.

In the early days of the campaign for cleaner milk it became clear that the provision of ample supplies of steam was one of the most important items on the dairy farm, especially when milking-machines came into more general use. Numerous experiments with the usual dairy utensils such as buckets, strainers, churns soon demonstrated the necessity not only for thorough washing with a detergent but also for efficient steaming to achieve bacteriological cleanliness. Steaming apparatus of various sorts, varying from adaptations of the simple farm copper to more elaborate low pressure boiler systems, soon became common on dairy farms.

For a very long time steam was looked upon as the only safe thing to use in sterilizing milking utensils—safe as regards efficiency, and safe in that it could not leave behind any residues which might get into the milk the next time the utensils were used. In fact, the use of chemical sterilizing agents in dairy utensils was forbidden in this country. But although steam properly applied has no equal as a sterilizer for milk production vessels it is not always the most convenient thing to produce or to use: a vigorous search for a safe and economical chemical sterilizing agent was consequently made by research stations in several countries, from which it appeared that chlorine offered most possibilities. Chlorine is a gas which is released from cer-

tain chemical compounds when wetted with water: the most widely used chlorine releasing compound in dairy work is sodium hypochlorite. Chlorine is very toxic to most bacteria which become thoroughly well exposed to it, but if bacteria are covered with a film of milk residues, as they may be in badly washed pails and other utensils, then the efficiency of sodium hypochlorite is much less than that of steam. It is therefore even more important that utensils shall be properly rinsed and washed where hypochlorites are used than when steam is used for sterilization. Naturally it is essential that the hypochlorite be used at the correct concentration, and makers of approved preparations have to guarantee not less than 9–12 per cent of available chlorine, not more than 2 per cent of free caustic alkali, and not less than 0·7 per cent of sodium chlorate. This last chemical is included because it is possible to detect it by a simple test, and thus find out if the hypochlorite is passing into the milk because of careless routine methods. It is only since 1943 that hypochlorites have been permitted for general use in this country as sterilizing agents for milk vessels.

In recent years bacteriologists have repeatedly stressed the importance of correct dairy routine in the production of milk of low bacterial content. They do not minimize the value of correct hygienic methods in the cowshed, but they point out that although primary contamination by bacteria comes from dust, hair, etc., this is negligible in comparison with the secondary contamination from bacteria which have multiplied in deposits of milk solids left in imperfectly cleansed and sterilized utensils.

It is almost impossible to destroy bacteria by exposure to even extreme cold, but at low temperatures bacteria develop slowly. For this reason the milk, which leaves the cow at body heat, is caused to run slowly over a corrugated metal cooler or refrigerator within which is a circulation of cold water. This should lower the temperature of the milk to about five degrees above that of the water. The temperature of the water used on many farms in the summer is often too high for satisfactory cooling of milk. Consequently milk coolers using artificially cooled water, or brine, or refrigerating gases such as ammonia

or sulphur dioxide are now being manufactured for farm use. The problem of cooling milk is also being tackled from another angle, that of immersing the churn in a cooling tank.

Particularly in summer it is impossible to maintain a low temperature during transit and distribution, and with rise in temperature there is an acceleration of the activity of bacteria. Beforc long enough lactic acid may be formed to cause the milk to go sour, or curdle, bringing about a dead loss, since such milk is unsaleable. The souring of milk, therefore, is seen to be a matter of initial contamination, temperature and lapse of time between production and consumption or processing.

Pasteurization offers a means of extending the keeping qualities of milk without seriously affecting its flavour, as well as destroying disease germs which are present. The importance of destroying such pathogenic bacteria needs no emphasis. There are two methods of pasteurization. The first, called the Holder Process, consists in exposing the milk to a temperature of 145 to 150 degrees F. for thirty minutes: in the second, called the High Temperature Short Time Process, the milk is exposed to a temperature of 162 degrees F. for fifteen to twenty seconds. In both processes the milk must subsequently be cooled at once to a temperature of not more than 55 degrees F. These times and temperatures have been arrived at after exhaustive experiments; as a result of these tests bacteriologists are satisfied that all disease germs, including the most heat resistant of all pathogens found in milk—the tuberculosis bacillus—are destroyed if the pasteurization processes are properly carried out.

Naturally the efficient pasteurization of large volumes of milk constituted an engineering problem of considerable complexity: how the technical difficulties have been solved is beyond the scope of this book, and reference must be made to the works mentioned at the end of this chapter. Another problem also required solution, namely, what checks can be applied to pasteurized milk to find out if the processing has been efficiently performed. The answer came from the researches of Kay and Graham who, between 1933 and 1938, devised the phosphatase test. Phosphatase is an enzyme which is always present in raw

milk, and it is more resistant to high temperature than even the most heat-resistant of the pathogenic organisms (i.e. of tuberculosis) likely to occur in milk. Consequently, if pasteurization destroys the phosphatase it is assumed that the milk has been effectively heat-treated. The presence or absence of phosphatase can be determined by a routine colorimetric test, and so highly is this regarded that any combination of time and temperature is now permissible for pasteurization provided the processed milk passes the phosphatase test.

Pasteurization correctly performed leaves the feeding value of milk virtually unaffected. Of course, if the temperature of the milk rises later and contamination with bacteria occurs, the milk is just as liable to go sour as untreated milk.

The numbers of bacteria in milk are estimated by a 'plate' method in which dilutions of milk are mixed up with an agar jelly in shallow glass dishes, the dishes then being incubated for several hours, or even days, at selected temperatures. Any bacteria present in the milk multiply rapidly, each single bacterium giving rise to descendants so numerous as to form a visible speck, or colony. By counting the colonies and multiplying by the dilution, an estimate of the number of bacteria present in 1 ml. (1 c.c.) of the original milk can be obtained. This method measures the number of bacteria in the milk, but even more important than numbers is the activity of the bacteria. This activity is now measured quite rapidly by the dye-reduction tests, i.e., the methylene blue and resazurin tests.

Dye reduction tests depend upon the fact that when bacteria multiply they bring about chemical changes which cause certain blue dyes to change colour from the original blue, through pink, to colourless. By noting the rate at which decolorization proceeds it is possible to estimate fairly accurately the activity of the bacteria in the milk. Methylene blue and resazurin are the dyes commonly used. In the resazurin test standard volumes of milk and resazurin in tubes are incubated at 37 degrees C. for the specified period. For examination, the tube containing the milk under test is placed in the left hand section, and a tube containing milk only is placed in the right hand section, of a

simple instrument called a comparator. A disc containing six coloured and numbered inserts is then rotated until the colour of the sample under test is matched on the disc: the milk is then said to have a disc reading of 1½ or 4 or whatever it is, the low readings indicating milk of poor bacteriological quality.

A special form of test called the Ten Minute Resazurin Test (The Rejection Test or Platform Test) has been found invaluable for preventing the contamination of bulk supplies by churns of milk of poor keeping quality. On arrival at the collecting dairy each churn of milk is inspected by the platform examiner: if he suspects, from appearance, or smell, or from previous records, that the milk is of doubtful quality he at once has it sampled and tested by the ten minute resazurin test. If the disc number is ½ or 0 the buyer refuses to accept the milk: if the disc number is 1 to 3½ the milk may be rejected or may be accepted by the factory for immediate processing if facilities permit. A disc number of 4 or higher indicates milk of market standard. The ten minute resazurin test is, of course, not the only form of platform test available for deciding whether milk shall be rejected or not. There are others, such as the clotting-on-boiling, the alcohol test, and the pH test, but the quick resazurin test has been found very satisfactory in practice.

In the methylene blue test the tube of milk containing the dye is incubated in a water bath at 37 degrees C. and is inspected at half-hourly intervals. Milk is regarded as satisfying the methylene blue reduction test if it fails to decolorize the methylene blue in 4½ hours in the summer months, and in 5½ hours in winter. This is the standard test for determining the keeping quality of designated milks.

Increasing knowledge of the behaviour of bacteria in milk and the development of simple tests for bacteriological quality made possible the inauguration of the National Milk Testing and Advisory Scheme during 1942. This scheme was introduced primarily to counteract the great wastage of milk which was taking place during the war years through premature souring, but it also provided an opportunity for extending advice to milk producers and handlers of milk generally. Its object was the routine

testing of the milk from every producer, with an additional platform rejection test on milk of doubtful quality upon arrival at depots, creameries and dairies. Since the introduction of new milk regulations in October 1949 the scope of the scheme has been modified, and its prime duty is now to test once a month the milk from all 'designated' producers by the methylene blue reduction test. Designated milks are Tuberculin Tested (T.T.) milk, T.T. (pasteurized) milk and Accredited milk.

Some bacteria are a nuisance in the dairy, whilst others are essential to the production of butter and cheese. In the making of butter, for example, cream is separated from the liquid portion by a mechanical separator, and must be allowed to 'ripen' before it can be churned. The ripening process is brought about by the development of lactic acid bacteria, which so affect the physical nature of the tiny fat globules in the cream that they cohere during churning. They also produce the desired flavour and aroma of the subsequent butter. The lactic acid bacteria form only a part of the bacterial population of milk, and it is quite possible for other forms to multiply and depress the lactic acid organisms. In such a case, ripening will not take place satisfactorily, and the amount and quality of the resultant butter are badly affected. To overcome this, and to ensure as far as possible a standard product, the practice of adding a 'starter' to cream is widely adopted. A starter is a culture of virile lactic acid organisms; when added to the cream these organisms develop so much acidity that the growth of other organisms is prevented, thus they ensure that ripening shall proceed on correct lines.

Ensilage, or the preservation of green fodder without first drying out the water it contains, has just come back into favour with farmers. Towards the end of the nineteenth century great interest was aroused in the making of silage from crops grown on arable land. Mixtures of oats, beans, barley, peas and vetches were commonly used, and when the leguminous plants were in flower the crop was cut in the field, hauled to the buildings, chopped into small pieces by machine and blown through a metal tube to the top of a tall tower called a silo. It dropped to the bottom of the tower and consolidated largely by its own

weight. As a result of certain 'fermentative' processes the fodder remained palatable for many months. Unfortunately ensilage was found to be more costly in labour than had been anticipated; in the absence of mechanical aids such as we have to-day, and with very little precise scientific information about the biological and chemical processes involved, and with imported feeding stuffs abundant and cheap, ensilage fell out of favour leaving many derelict tower silos dotted about the countryside. A revival of interest took place in the early 1930's, following Woodman's discovery that young grass is very rich in protein. It was sought to preserve this young grass by turning it into silage, but early attempts resulted in a very inferior product, evil smelling and 'sour'—the butyric type of silage. The observation that 15 to 20 per cent of dried sugar beet pulp added to the young grass produced a palatable silage, led to the discovery that young grass and leguminous plants do not contain enough easily fermentable carbohydrate for efficient ensilage purposes. For the preservation of green fodder depends upon the rapid development of lactic acid, formed when certain bacteria feed upon sugary material. The organisms produce so much lactic acid in favourable conditions that they are actually destroyed by it and the acid acts as a preservative. Consequently the technique was developed of adding about 20 lb. of molasses per ton of young grass as it was filled into the silo, and this greatly assisted the manufacture of good quality grass silage.

From about 1925 an alternative process of silage making was developed by Professor A. I. Virtanen in Finland. In this system the preservation of the green fodder is brought about by adding to it a mixture of hydrochloric and sulphuric acids. The composition and amount of the acid differ for different crops: recommendations are based upon numerous experiments and have to be followed closely to get the best results. This A.I.V. method is widely practised in Scandinavian countries; the directly acidified silage is palatable and appears to have no ill effects upon animals consuming it, though it is necessary to feed ground chalk with it. On the other hand the use of mineral acids necessitates taking certain precautions such as the wearing of protective clothing

and rubber boots, the use of bituminous paint on the inside of concrete silos and so on. Although tried out on a small scale in this country before 1939, the method did not catch on.

When war broke out in 1939 strenuous efforts were made to popularize the manufacture of high protein molassed silage from young grass to take the place of concentrated foods which were no longer available. A certain measure of success was achieved, but the type of container or silo advocated was often very unsatisfactory, and methods of handling were wasteful of time and labour. So many tons of inferior silage were made that enthusiasm waned, and the countryside once again became dotted about with unused silos—though of a different type. About 1945 the advantages of the pit silo became more widely appreciated. The pit silo is merely a rectangular pit with slightly sloping sides and sloping ends. It can be excavated very cheaply by mechanical means, and can be filled with much less labour than most tower silos. In addition it is possible to consolidate the green material very much more efficiently in a pit than in a tower silo, by running a tractor over the material as it is filled in. Furthermore, if the grass is cut just as it comes into head instead of in the very young stage, molasses is not essential and a bigger weight of protein per acre is obtainable. These advantages, plus the very small wastage usually experienced, have led to a remarkable revival of interest in grass silage. On some farms it is ousting haymaking altogether, for silage is so much less dependent upon good weather than hay and makes less exacting demands upon the farm labour force. In some districts, especially those where a high water table makes it impossible to use pits, silage is made in huge stacks or clamps. If the sides of these stacks are kept well pulled the wastage is not excessive, and cutting out the material before feeding is certainly easier from a clamp than a pit.

Marrow stem kale is surprisingly rich in protein and a good crop may yield as much as 9 cwt. of crude protein per acre compared with the 4 cwt. provided by a crop of beans. The practice is growing of ensiling kale in October or early November when the crop is at its best: although the crop loses about one-third

or one-half its dry weight during chopping and storage, these losses are offset by the convenience in handling and the insurance against almost total loss of crop which may occur during a hard winter.

One of the most spectacular developments of recent times has been the control of weeds growing in cereal crops. Since 1940 very remarkable progress has been made, but as Blackman has pointed out, the work began about 1896 when Bonnet in France showed that a 3 per cent solution of copper sulphate sprayed on a cereal crop infested with charlock would destroy the weed without seriously damaging the corn. The success of the operation depended very much upon the prevalence of dry weather for some days after spraying, but for over thirty years copper sulphate was the only material at all widely used for weed destruction in cereals in this country. Strong solutions of sulphate of ammonia, 1–2 cwt. dissolved in 50–60 gallons of water, were used on a very limited scale: certain fertilizers in powder form, notably calcium cynamide and finely ground kainit, were used on calm dewy mornings with some success. But here again, good weather was essential to success. About 1911 Rabaté in France demonstrated the efficacy of a 7–10 per cent concentration of sulphuric acid in controlling both white and yellow charlock in corn crops, and the system gained popularity here some twenty years later. The acid was a much more certain killer of weeds than any of the materials previously tried and success was almost independent of the weather. The check to the cereal was appreciable, but the crop improved rapidly once the competition of the weed had been removed.

In all these instances the 'selective' action of the chemical is due to differences in the nature of the leaves of the weed and the cereal. Cereals have leaves which are long and narrow and held more or less vertical: they are smooth and covered with a waxy material. Charlock and most other annual weeds have broad, often hairy leaves held more or less horizontal. Sprays are consequently more apt to remain on the foliage of the weeds than on that of the cereals, and their corrosive action is therefore prolonged.

But in 1932, Truffaut and Pastac, also in France, began experimenting with dinitro-ortho-cresol, a yellow dye which in petroleum emulsions was becoming popular for destroying certain insect and allied pests of fruit trees (see Chapter Five). It was found that DNC in water suspensions was more selective than anything yet tried, and would kill a great variety of weeds without checking the growth of the cereal. The increase in the tillage acreage during the food production campaign of 1939 onwards led to a tremendous development in DNC spraying, and the use of the more soluble sodium and ammonium salts also increased. The chief disadvantages of DNC are its penetrating yellow stain, which makes it unpleasant to handle, and its poisonous nature. But it does not corrode metals and is not usually so dangerous to handle as sulphuric acid.

From 1943 onwards an entirely new class of selective weed-killer became available, the so-called 'hormone' weedicides: their history is worth detailing for it illustrates very well how small observations of apparently academic interest only can lead to developments of great general importance. The story begins with the observation that the young shoot, or coleoptile, of an oat seedling grown in a room, always bends over towards the light. Some seventy years ago Charles Darwin recorded the fact that if the tip of the shoot is cut off, the shoot does not curve over. Later it was found that if the tip of a coleoptile is cut off and is replaced with a thin sheet of agar jelly between it and the rest of the shoot, the sensitivity of the shoot to light is not affected. Further, if a shoot is decapitated and then has placed upon it a sheet of agar upon which coleoptile tips have been standing for some time, it will respond to light in the normal way. From this sort of experiment it became clear that the tip must secrete a substance which regulates the growth of the shoot, causing the non-illuminated side to grow faster than the lighted side and so bring about a curvature.

It had also been observed that if human urine came in contact with oat seedlings, similar curvatures were brought about. By 1933 research workers had isolated from urine two plant growth regulators which were named auxin *a* and auxin *b*: in 1934 they

isolated a third, called hetero-auxin, which appeared to be none other than the organic compound known as beta-indolyl acetic acid. Later it was proved that these compounds exist in plants.

The fact that it was possible to synthesize hetero-auxin (and also other plant growth regulators discovered later) led to much research upon the effects of these substances. It was found, for example, that alpha-naphthyl acetic acid could stimulate the production of roots from certain kinds of plant cuttings, and in a very short time this preparation was marketed for general use. In 1940, at the Imperial Chemical Industries experimental station in Berkshire, Templeman carried out an experiment with alpha-naphthyl acetic acid, spraying a solution over boxes of soil containing in the one case seeds, and in another plants, of oats and charlock mixed. He found that the chemical almost entirely suppressed the germination of the charlock seed but did not affect the oats: it killed the charlock but appeared not to harm the oat plants.

In these experiments the minimum dosage was 10 lb. of the growth substance per acre, and as this is very expensive to manufacture it was not an economic proposition on a farm scale. But very intensive research revealed numerous substances much more powerful and by 1942 two of these were selected for further trial. They were tried out on a field scale all over the country in 1945, and have since become accepted by the farming community as a great aid in weed control. The two substances are 2-methyl-4 chlorophenocyacetic acid, also known as methoxone or MCPA; and 2 : 4 dichlorophenoxyacetic acid, or DCPA, or 2 : 4-D. Both these growth regulating substances are very potent indeed. Under experimental conditions a few ounces per acre are sufficient to destroy all plants of charlock. Under farm conditions about 1 lb. of the active material per acre applied as a spray, or about twice this amount when used in a dust, are the usual recommendations for charlock. The substances are non-poisonous, non-corrosive. They have remarkable effects upon some plants, causing the stems to twist, swell or become distorted. Weather conditions are of little consequence, for the material is absorbed both by roots and leaves; yet the effects of

the growth substances are lost within a few weeks so that a following crop is not influenced.

These growth regulating substances leaped into popularity, particularly in America where 2 : 4-D has been used over enormous acreages during the last four or five years. Yet it is quite clear that while these 'hormones' give an excellent control of yellow charlock, wild radish, shepherd's purse, corn buttercup and some other weeds, they are not so efficient against cleavers, may-weed, corn marigold and some other species which are better controlled with DNOC or sulphuric acid. They are a most useful aid in weed control but they are certainly not the final answer: many other growth substances are under test including 2-4-5 trichloro phenoxy acetic acid (TCPA), which is capable of destroying shrubby plants; more recent developments in selective weedicides include dinitro-secondary-butyl phenol, which is used to control weeds in peas and flax. It is known that certain chemicals such as the carbamates will kill grasses without harming broad-leaved plants, but at present they are too expensive to use on a farm scale. It is known, too, that different chemical forms of MCPA and DCPA act differently on plants. At first, the sodium salts were extensively used, but more recently the amines and esters have been increasingly utilized. The most satisfactory ways of using these different materials in the field are still a matter for experiment.

The use of 'hormones' or growth regulating substances in agriculture and horticulture is not confined to selective weed-killers. The stimulation of root formation on herbaceous and woody cuttings has already been mentioned. The development of fruit without pollination and fertilization can be brought about by the use of alpha-naphthoxy-acetic acid (as well as by other chemicals of the same type). This procedure is now being used on a commercial scale to obtain fruit from the lower trusses of tomato plants, which at times do not 'set' very well. The routine is to spray the open flowers with a dilution in water of approximately 40 parts per million of the chemical: the resultant tomatoes are similar in external appearance to normal fruits, but are seedless and not quite identical in internal structure.

Another interesting use of hormone-type chemicals is the prevention of pre-harvest drop in apples and pears. It frequently happens that certain varieties of apples fall off the tree before they are properly ripe, especially in windy weather. If the stalks of the apples are thoroughly wetted with alpha-naphthalene-acetic acid two weeks or more before the normal date of picking, the formation of the abscission layer at the base of the stalks which precedes fruit drop is prevented, and the fruit remains attached to the tree. In fact the treatment can be so successful in preventing fruit drop that the apples may prove very difficult to pick.

It is possible, also, to delay the bursting of buds by applications of alpha-naphthalene-acetic acid, and this may be of importance if it is found possible on an orchard scale so to delay bud growth that frost damage can be avoided.

With potatoes the vapour of methyl-alpha-naphthalene-acetic acid (MANA) has been found to delay sprouting of the tubers very considerably. Since potatoes lose from 20 to 25 per cent of their weight through sprouting if stored until midsummer, it is obvious that a sprout repressant has commercial possibilities. It so happens that MANA is not only expensive but inconvenient to use. But other chemicals, the chlorinated nitrobenzenes, show more promise. Their efficacy as sprout repressants was quite accidentally discovered, because the primary reason for experimenting with them was to obtain a means of controlling dry rot of seed potato tubers (see p. 115). But it is now well established that tetra-chloronitrobenzene and associated compounds scattered in the form of a dust over tubers stored in clamps or other confined spaces will delay the sprouting or chitting of the tubers, and the materials are sufficiently cheap to make the treatment commercially possible. Since the discovery is very recent indeed a lot remains to be learned about the best way of using the sprout repressants: some growers have already found that the material can in some circumstances act only too well upon seed of the early varieties of potato, causing delayed growth and a late 'lift' of tubers in the crop: more information is required about the optimum rate and time of application.

Some interesting things about earthworms have been discovered of late. For a long time, certainly since the writings of Gilbert White in 1777, it has been commonly believed that earthworms are necessary to a fertile soil: recent research has thrown some doubt upon this hypothesis. Darwin's estimate of 50,000 earthworms per acre of garden soil has been shown to be an under-estimate for many field soils, where populations of from 100,000 in arable land to 1,000,000 per acre in old pasture have been encountered. The surprising fact has been elicited that the weight of worms in a pasture (12 cwt. per acre) may be as great as the weight of stock that the pasture can feed, and the activities of worms in draining, aerating and pulverizing soil in grassland must have considerable effects. But in arable land these operations are done more rapidly and extensively by the plough and implements of cultivation, so that under the highly artificial conditions of arable farming earthworms probably have little influence in the soil. It has proved almost impossible to determine accurately whether plants grow better when earthworms are present in a soil or when they are absent. In the artificial conditions of a trial earthworms have a habit of dying, and when they decay they fertilize the plants and so upset the experiment!

During the last twenty-five years agricultural scientists have made increasing use of statistical methods in their experimental work, which have given them much more reliable information than was formerly available. The experimenter comes up against numerous difficulties in field work. The first is weather conditions, which make it inadvisable to rely too much upon results obtained in one season only. This means that a particular trial should be repeated for at least two more seasons if reliable conclusions are to be drawn. Secondly, no patch of ground is absolutely uniform; no matter how uniform and even it may appear, small variations exist, and these will be reflected in the crop. Third, small variations in cultivation, drilling, manuring and so on are inevitable. Consequently, really accurate results from an experiment—designed, say, to find out the effect of different manurial dressings—cannot be obtained from large single plots. It is not sufficient, that is, to split a field into three plots, apply

different manures to each plot, weigh the crop and say that dressing number one is superior to dressing number two. A large number of experiments have been conducted on these lines, but considered by itself such a trial can be exceedingly misleading.

Nowadays field trials are based on two main principles, namely randomization and replication (or repetition) of plots, since it is impossible to rely upon results from a single plot for each treatment because of soil variations. Then the choice of treatment to go on each plot must be left entirely to chance—this is called randomization—for conscious selection might give a false result. A third principle, local control, enters into the layout, to ensure that all plots of one particular treatment do not by chance occupy one particular corner of the experiment. When the crop yields for the various plots have been obtained, the statistician is able to calculate the 'experimental error' and estimate the effects of the various treatments. The calculations cannot be described here, but they have been designed to iron out soil and other differences and provide an accurate estimation of the effect of responses to the treatments under test. They have been available only about twenty years, and were devised by R. A. Fisher at Rothamsted.

COLLATERAL READING

For an introduction to the study of bacteria see *Microbes by the Million*, by Hugh Nicol (Penguin, 1945). The behaviour of soil bacteria is explained in *Soil Conditions and Plant Growth*, by Sir E. J. Russell (Longmans, Green, 1942). An introduction to the bacteriology of milk, as well as all sorts of information about the testing and handling of milk and milk products, is provided in *Dairy Information*, by H. B. Cronshaw (Dairy Industries, 1947). *The Pasteurization of Milk*, by G. S. Wilson (Ed. Arnold, 1943) sets out the argument for this process: consult also *Bacteria in relation to the Milk Supply*, by C. H. Chalmers (Ed. Arnold, 1945). *The Handling of Milk and Milk Products* (Bulletin 3, Ministry of Agriculture, 1937) gives useful information.

An account of the plant growth substances, as the subject was understood in 1947, is given in *Growth Regulators*, by J. W. Mitchell and P. C. Marth (C.U.P., 1947). For accounts of methods of weed destruction refer to *Weed Control*, by G. H. Bates (Spon, 1949) and *Suppression of Weeds by*

Fertilizers and Chemicals, by H. C. Long and Winifred E. Brenchley (Crosby Lockwood, 1946).

For books on composts refer to the list given at the end of Chapter Two: *Darwin on Humus and the Earthworm* (Faber and Faber, 1947) should also be consulted.

Books on statistical methods are usually heavy reading for the amateur but a start may be made with John Wishart's *Field Trials: their Layout and Statistical Analysis* (Imperial Bureau of Plant Breeding and Genetics, 1940), and followed up with K. Mather's *Statistical Analysis in Biology* (Methuen, 1946).

Chapter Ten

THE WORK OF THE ENGINEER

Influence of the internal combustion engine—steam—the tractor—speed and convenience of working—types—pneumatic tyres—tractor: a mobile power unit—unit principle of mounting implements—drainage machinery—grain harvesting machinery—the combine harvester—drying and storing grain—disposal of straw—straw and hay balers—sugar beet seed—sheared seed—decorticated seed—drilling sugar beet—pelleted seed—harvesting beet—harvesting potatoes—combined seed and fertilizer drill—planting-machines—the hammer mill—weed spraying machines—spraying problems—grass drying—advantages of dried grass—grass driers—grass meal and grass cubes—milking-machine—open-air milking—lighting of poultry houses—electric fence—rotary cultivation.

The development of the internal combustion engine has had a greater influence upon farming than any other single factor during the last thirty years. Farming is very largely a matter of applying power to the land or to operations in and around buildings. On purely grass farms very little power is required, but on large mixed farms a great deal is necessary. Man-power, oxen-power, and horse-power have been used for thousands of years, and with the invention of the wheel it became possible to utilize the wind and water as sources of energy. Until the invention of the steam-engine about two hundred years ago there were no other sources of power, and steam-engines were so costly and cumbersome, and their radius of

effective action so small, that very few farms were able to utilize the power of steam.

Of course steam exercised an influence on agriculture as it did upon all sections of national life. Improvements in communication, which began with the canal era, were continued by the railways, and this meant larger markets; incidentally it opened up native farming to competition from the whole world. Laborious operations like threshing, previously carried out by teams of men and women, could be performed by peripatetic steam threshing tackle. Ploughing on really stiff land was accelerated by steam ploughs, and so on. But steam was not available where and when it was wanted on the farm, and so exercised chiefly an indirect influence.

The internal combustion engine, however, has made it possible to take power to almost any part of the farm. It has not only made it possible to perform certain stationary tasks, such as pumping, grinding, and sawing, very much more rapidly, thus taking much of the drudgery out of the farm work, but it has also had a considerable influence upon the cultivation of the soil and the harvesting of crops.

In the first edition of this book which appeared in 1938 the statement was made "that to the average townsman the oil engine in agriculture is associated with the farm tractor, but the latter is at the moment possibly of minor importance compared with the portable stationary engine. There is scarcely a farm which does not use a fixed oil engine of some sort, whilst tractors are by no means universally employed."

This statement is no longer true because during the last twelve years there has been an enormous increase in the number of tractors used on British farms, so much so that for its size this country has a more highly mechanized agriculture than any other. There are now over 300,000 tractors in use on British farms to-day, compared with 46,000 in 1937. There are several reasons why the tractor has replaced the horse as the chief source of power in cultivating the land, but perhaps the most important one is the ability of the tractor to do a lot of work in a short space of time. This is a very valuable feature, especially to a

man farming stiff soil, since weather conditions play such a dominating part in the cultivation of strong land. The ability of a machine to do the right job at the right time gives it a superiority over the power of horses, especially on large farms. With relays of drivers a tractor will work almost without ceasing, whereas horses as well as men become tired and must rest. This feature is of value not only in ploughing but also at hay harvest and corn harvest, seasons of the year which have always been hard on horses. The horse-drawn binder, for example, is exhausting work for animals working in heat and plagued with flies, whereas the tractor treats the binder as merely a moderate load.

A further reason is that the largest modern tractors can tackle jobs which are impossible to horses, like much of the reclamation work hurriedly put into operation at the beginning of 1940. Horse labour could not have replaced the bulldozer, deep-digging plough and excavator of ditches. At the same time there are still many jobs about the farm which can be more economically carried out by a horse than a tractor, which is why on many medium-sized holdings both horses and tractors are to be found. On the other hand mere economy of operation is not always of supreme importance: convenience also must be considered. This is why on many smaller farms a tractor has replaced the horse team. With shortage of labour it is sometimes not convenient to keep horses, which require looking after every day of the week, whereas a tractor can be left at week-ends and similar occasions. One further point is worth mentioning: a horse requires the produce of about three acres of land for its maintenance during the year—grass, oats, beans, etc.—so that the usual two-horse team locks up the produce of six acres. Conversely, a tractor does not make any manure.

Although it is possible to speak of tractors in a general way, yet it must be remembered they are extremely variable in size and power. The engineer has developed at one extreme enormous track laying machines of 100 brake horse power and weighing many tons, and at the other extreme is evolving very small, light, single-wheeled machines having engines of less than one

horse power. Most of the tractors used in this country are of about 20–25 b.h.p. (brake horse power) and are fitted with four wheels. In the early days farm tractors had steel wheels only but nowadays the standard equipment is usually pneumatic-tyred wheels, with a set of steel wheels which can be fitted when soil conditions are too bad for rubber tyres, i.e. when wheel spin may be expected, as on very light land or on stiff land when it is wet. For haulage work in very awkward conditions, such as steep hillsides or very heavy clay soils, track laying equipment has become popular, for it gives good adhesion without undue compression of the soil. It is now possible to buy conversion sets whereby a standard-wheeled tractor can be turned into a 'half track' machine.

It is only natural that the early tractors should be looked upon merely as pulling agents, able to take the place of horses in hauling field implements and road vehicles. During the last decade or so, however, this conception of the duties of a tractor has become very out-of-date. The modern tractor is becoming increasingly regarded as a mobile power unit capable of performing a variety of different forms of work. In addition to straightforward hauling jobs such as ploughing and cultivating, it must be able to do stationary work from the belt pulley such as threshing, sawing and pumping: it must be able to supply power from the power-take-off to drive machines like mowers, binders and small combine harvesters: and it must have hydraulic or other gear for lifting and raising implements such as unit mounted ploughs, buck-rakes, sack loaders and so forth. Naturally, the modern tractor is a much more complicated machine than the tractor of thirty years ago, but despite this it is a handier, more reliable outfit, and often it is much lighter as well as being more powerful.

Since the early tractors were used almost entirely to replace horses, the design and method of attachment of the first tractor implements, ploughs, cultivators, hoes, etc., were much the same as those used for very many years for horse work. That is, all the implements were separate from the tractor and were of the trailer type. But the modern trend is to mount the implements

of cultivation direct upon the tractor, either at the rear, under the 'belly' or even at the front of the machine. Thus several makes of tractor of light to medium horse power have ploughs attached on this 'unit-principle', and because the ploughs can be raised and lowered by the hydraulic lift mechanism, ploughing is made appreciably faster and much more convenient through reduction in time occupied in turning at the headlands. Also there is a saving in time in transport from farm to field, since the plough has merely to be raised automatically for the tractor to move off in the same way as an independent machine. Incidentally unit-mounted 'one-way' ploughs of two-furrow type are now being developed, since if land can be ploughed 'one-way' the open furrows so characteristic of traditional systems of ploughing are eliminated. The abolition of these furrows simplifies after-cultivations, and for such crops as sugar beet, carrots and many market garden crops, the greater evenness of the surface enables much more accurate hoeing to be performed.

The need for precision in cultivating and hoeing (i.e. for row-crop work generally) has affected the design of tractors in several ways. In the first place the operator's seat is now being placed higher and more in the middle of the tractor than formerly so that the operator can see clearly where he is going. There is a tendency also for this class of row-crop tractor to be built higher to give more clearance. Then the implements for row-crop work are, as already mentioned, carried on the tractor attached to a tool-bar. In the best systems the individual tools, such as hoe blades, are independently sprung so as to overcome inequalities in the surface of the soil. Some manufacturers fit the tool bars at the rear of the tractor, some have mid tool bars, others fit front tool bars. There are advantages and disadvantages in each system.

The application of the internal combustion engine to farm drainage machinery has had spectacular results since 1939. It is now well-known that very large areas of farmland fell out of cultivation, or deteriorated as pasture, during the years preceding the war because of the collapse of farm drainage systems, the blocking of ditches, and the general neglect of watercourses.

Fields became waterlogged, flooding was common, and satisfactory growth of crops and grass became impossible. One of the first tasks in reclamation was to clear the watercourses: when the trees and bushes alongside these courses had been removed by hand labour it was possible to use mechanical excavators to dredge out the silt which had accumulated for generations These machines can do the work of many men, and the quantity of material they have dug out of watercourses and ditches is incredibly great. By the use of a side-drag line it became possible to clear ditches so small and so awkwardly placed that they had hitherto been considered beyond the scope of a mechanical digger. Frequently these excavators in cleaning out ditches disclosed the main outlets of forgotten field drainage systems, covered up by four, five or six feet of accumulated rubbish: in many cases these drains resumed their function of releasing subsoil water as soon as their outlets had been cleared.

Mechanical power has also been applied to the digging of the narrow trenches required for the laying of pipe drains on the farm. This had been attempted for a long time, but without much success: but recently several trench-cutting machines have been successfully employed, and the trenches they cut for the reception of drainage pipes compare very favourably with the best of those laboriously cut by hand. The labour of filling in the trenches on top of the pipes has similarly been greatly reduced by the use of a small bulldozing tractor. This can push most of the excavated soil back into the trench in a fraction of the time needed by hand labour. A still further development in land drainage is the complete tile draining machine. This not only cuts a tunnel at the right distance below the surface of the ground, but automatically places in position the drainage pipes fed to it from above. Naturally, the draught of these machines is considerable, and they are still in the development state, though some good work has been done by certain types.

Another form of drainage which has been greatly developed recently is mole drainage. This is carried out only on soils with a retentive subsoil, such as clays and marls free from large numbers of stones. The mole is a short pointed rod of steel about

three inches in diameter, to which is attached by a short chain a conical bob: the rod is fastened to a strong steel plate some three feet long. The plate, with a sharpened front edge, is carried on a wheeled chassis, and the mole is dragged through the subsoil at a previously determined depth. It leaves behind a narrow cylindrical tunnel which in suitable soils will retain its shape for several years, acting as an unlined drainage channel. Of course, suitable exits have to be provided for the water. Mole drainage, thanks to the track-laying tractor, is relatively cheap, and although not so enduring as tile drainage, it can be repeated at intervals at not too great a cost, especially where well-planned tiled main drains are included in the scheme.

An ingenious use of the mole plough has been made in connection with piped water supplied to pasture fields. To overcome the labour and expense of digging trenches for galvanized pipes, the pipes themselves are screwed together in long lengths, and are then pulled into the ground behind a mole plough: flexible plastic pipes are also available. On suitable land the operation of pipe laying can be very expeditiously carried out in this manner, and there is the additional advantage that the inconvenience and messiness of open trenches are eliminated.

The harvesting of grain has been profoundly influenced by the engineer during the present century. In the early days of systematic farming grain was harvested with the sickle: the ears were severed just below the head, and later the straw was cut off just above ground level in a separate operation. The grain was knocked out by hand-operated flails. Later, harvesting with the scythe was practised and continued right up to the beginning of the twentieth century. But from the middle to the end of the nineteenth century various kinds of mechanical harvesters were invented and these became more or less standardized in the 'binder', which included a straw-cutting device and a mechanical knotter which tied up the corn into bundles or sheaves. Corn is always cut with a binder before it is completely ripe so as to avoid loss through shedding or shattering of the grain, and it is necessary to stand the sheaves upright in stooks to allow the grain to harden and the green 'rubbish' in the base of the sheaves

to shrivel and die. If this is not done there is danger of excessive heating in the stack when the sheaves are collected and ricked. After a period in the stack, the grain is threshed out by a threshing-machine, and it is then sufficiently dry to be stored quite safely if it is not required for immediate use.

The binder is still the most widely used mechanical device for harvesting grain in this country, but it involves much labour. In America and Australia, where the labour available in relation to the acreage under corn has always been less than in this country, strenuous efforts were made from the 1920's onwards to develop reliable machines which would cut and thresh corn in one continuous operation: these have now reached a considerable degree of efficiency, and are known as combine harvesters. They were introduced into this country in the early 1930's and have become very popular indeed since 1940, when food production during the war was an urgent task.

The combine harvester comprises a reciprocating knife to cut the straw, a drum to thresh the grain, moving riddles, revolving fans to produce an air blast to separate the chaff, weed seeds, etc., and a means of throwing out the threshed straw. The smaller machines are drawn by a tractor and may be actuated either by the power take-off shaft of the tractor or by a separate engine on the combine. The larger machines with cutter bars from 8–12 feet wide are usually self-propelled, i.e. they require no tractor to haul them. It is usually estimated that a combine harvester should be able to deal with at least 15 acres per foot of cutter bar. That is, a combine with an 8 ft. cutter bar should harvest not less than 120 acres of corn in a season: in many districts combine harvesters deal with more than twenty-five acres per foot of cutter bar.

A harvester-thresher working on an entirely new principle has recently been developed. In this machine the ears of the standing corn are guided between revolving plates which, together with the suction produced by a fan, rub out and extract the grain, plus some of the chaff, without severing or removing the ears. The straw is left standing and from a distance the harvested crop appears almost normal. The straw can be harvested

with a binder, in which case it is of first-class quality since it is unbroken and ideal for thatching—or it may be ploughed under or turned under by some form of rotary implement. This machine in its simplest form has only two or three moving parts.

The introduction of the combine harvester has brought several new problems in its train. In the first place there is a demand for cereals, especially wheat and barley, with a stiff, rigid straw which will stand upright and not flop over, or lodge, since a laid crop is more difficult to harvest than an upstanding one. Next, there is a call for crops which will not shatter, or shed their grain, as they ripen. It is quite essential, when harvesting with a combine, for the grain to be dead ripe. This is so because unripe grain will not thresh out easily, nor will it store in good condition when knocked out of the straw. Some varieties of wheat, for example, shatter more easily than others, and the loss may be considerable.

Then there is the problem of the moisture content of combine harvested grain. Grain will not store very well in bulk if its moisture content is much in excess of about 14 to 16 per cent, yet wheat as combine harvested may, in damp weather, have as much as 25 per cent or even 30 per cent of moisture. Recent investigations have shown that standing corn both absorbs and loses moisture very readily at harvest, and that by taking advantage of sunshine and drying winds, grain with only a moderate amount of excess moisture can be harvested if patience be exercised. Nevertheless, a lot of grain comes from the combine altogether too moist for safe storage and must first be artificially dried. Grain driers of various patterns are available, some horizontal, some vertical, but the principle in them all is the same. A current of warm air is blown through the thin layer of grain, and the moisture content is reduced to safe limits. Grain intended for seed and barley destined for malting must be dried with great care or its vitality may be impaired. Very moist grain may have to be passed two or more times through the drier, for it is very detrimental to the embryo of grain to expose it to air at too high a temperature in an effort to remove all the moisture excess in one operation. Users of the smaller combines which

deliver the grain into sacks instead of large collecting tanks are having offered to them simple driers in which warmed air is blown through the sacks of grain as they lie over gratings in a horizontal flue.

The problem of grain storage is fast becoming serious because of the increase in numbers of combine harvesters. When corn was harvested by binder and stored in ricks on the farm there was no urgency, other than financial considerations, to market the grain. The crop could be threshed out and sold according to the needs of the markets. But owing to the combine harvester a considerable proportion of the crop is thrown upon the market within the space of six or eight weeks in late summer and early autumn, since few farmers have facilities for the bulk storage of grain, especially grain of high moisture content. A proportion can be taken up by the millers and merchants and some can be stored at Government silos, but the amount which can be absorbed in these ways is relatively small. Consequently attention is now being directed towards cheap and satisfactory methods of constructing storage bins on farms. Pneumatic conveyors for the grain and means for blowing air through the bins are two of the points under consideration.

Another problem set by the combine harvester is the disposal of the straw which emerges in a rather battered condition from the rear of the machine. In America and Australia the usual practice has been to burn the straw, and this is sometimes done here as well because of the difficulty of ploughing it in. To burn straw, however, is to lose the bulky organic portion which consists very largely of carbon obtained from the atmosphere during photosynthesis: this organic material turns to humus in the soil (see p. 32) and helps to maintain the physical condition and fertility of the land. Burning straw is consequently not much favoured by British farmers. One way out of the difficulty is to tie the straw up into tight bales by means of a pick-up baler following the combine, and remove the bales to the fold yard or farm buildings for foddering or for use as litter. Those farmers who wish to plough in the straw can fit a straw spreader to the combine. This is a revolving paddle or propellor which

to some degree scatters the straw instead of allowing it to fall in a thick broad layer behind the combine. Even so the straw is not easy to plough in, though certain ploughs of the disc type with certain modifications will make a good job of it. An alternative is to scatter mustard seed over the straw. Some weeks later when the seedlings grow through they bind the loose straws together and prevent it from 'reeving up' in front of the plough: in this way it is possible to bury the straw fairly neatly. The use of rotary implements may assist in burying straw (see p. 216).

Until comparatively recently the only way of baling hay or straw was by hand-operated machines which had a very low output. Then, stationary balers worked from the belt pulley of a tractor were developed. These were very satisfactory if the straw or hay were loaded in from a rick or large heap, or could be swept up to the baler in the field. But for use in the hay field or behind a combine harvester the stationary baler had disadvantages, and the next development was the 'pick-up' baler. This machine is able to pick up hay from the windrow or straw from the combine and transfer it to a chamber where it is compressed by a reciprocating piston and fed continuously into a rectangular tube. Wires are inserted at intervals and twisted together so that as the hay is forced out of the channel it forms separate bales. All this goes on while the baler is in motion. Unfortunately it requires several men to operate an ordinary pick-up baler, and to cut down labour, fully automatic pick-up balers have been invented. These pick up the fodder, compress it and tie it without human assistance. A point worthy of note is that baling wire is being replaced more and more by baling twine—a very acceptable move, since baling wire is a terrible nuisance on a farm once it has been cut away from the bales and lies about tripping people up and getting in the way generally.

The sugar beet crop has received much attention from engineers since the 1920's, for it is one which needs a lot of care on the part of the farmer if it is to be really profitable. The farmer's troubles start right from the very sowing of the seed—if for our present purpose we ignore the painstaking cultivations which precede the formation of a very fine, very firm tilth so essential

to an even germination of seed. The seed of sugar beet is really a cluster of two or three seeds surrounded by a woody core: when germination takes place there may be one solitary seedling, or two or perhaps three seedlings crowded together. These 'doubles' are a nuisance to the farmer, for they are difficult to thin out or 'single': in consequence, repeated efforts have been made to split up the cluster into individual seeds by mechanical means. About 1944 sheared seed was introduced: it was produced by the action of an abrasive disc on beet seed held against a plate. It took about three pounds of natural seed to produce one pound of sheared seed, and the germination of the latter was not very satisfactory: there were also many doubles, and after a short burst of publicity sheared seed lost favour. A modified process which gives rise to decorticated seed has now been developed: here only two pounds of natural seed are needed to give one pound of decorticated seed, and the farmer may reasonably expect about 60 per cent of single plants from it.

Having got the seed the next problem is to drill it accurately and at constant depth. The ideal way would be to space each seed a specified distance from its neighbours, and engineers are hard at work on this very difficult problem. One method of obtaining even depth is to have a number of small independent drills attached to a tool-bar instead of the usual large drill with numerous coulters. Variation in seed and inequalities in the soil obviously complicate the issue. When the seedlings are up, very close and accurate mechanical hoeing is desirable: hoes mounted on tool-bars as described on page 200 are capable of very good work. Efforts are continually being made to devise mechanical means of gapping, or of cross-blocking, the plants in the row to save hand labour, with varying degrees of success.

Since both natural seed and processed seed have rough surfaces the problem of even drilling is a difficult one to solve. In an attempt to simplify the matter the processed seed has been coated with material to give it a spherical shape with a smooth surface. The materials used must, of course, disintegrate in the soil so as not to interfere with germination. The idea of pelleting beet seed is very attractive, but so far the seedlings from this

kind of seed have been slow in appearing and rather weak in growth. Further investigations are needed.

The harvesting of sugar beet has exercised the ingenuity of engineers for the last thirty years. The task has been approached in two different ways. One school seeks to mechanize the whole series of operations through a single complicated machine which will top, lift, clean and load the beet into trailers or wagons. The other looks for two, or possibly more, simple, inexpensive machines which will each do part of the job well. A considerable amount of success has been achieved with both systems, but it is clear that there is much room for development, especially if the artificial drying of beet tops becomes widespread.

Potato-harvesting machinery, too, has received much thought because of the greatly increased area devoted to potatoes during the war years. Hitherto, most of the lifting devices have been of the spinner type, the tubers being knocked out of the soil by revolving tines. Lately, machines of the elevator type have been produced in some variety; here the tubers are lifted by a broad, flat, sloping blade, and transferred to an elevator which drops the potatoes in a narrow continuous row on top of the soil, leaving them in a much more handy position for picking up. It may at first sight appear foolish to elevate the tubers and then drop them back on to the ground: but so far it has not been possible to devise a cheap and satisfactory method of separating potatoes from stones during the lifting process, and this has naturally held back the development of potato-diggers, though some of the more expensive machines do the separation fairly well. A number of machines which essay the whole task of lifting, cleaning and bagging potatoes have been designed and demonstrated, but so far none has come into general use.

A development of great importance, already referred to on page 42, is the so-called combine drill—an implement which sows both seed and fertilizer in one operation. Seed and fertilizer are carried in separate containers, but both are deposited in the same coulter mark. One type of combine drill deposits the two things down separate tubes, whilst another mixes seed and fertilizer as they drop down a single delivery tube. It has been

shown that many farm crops benefit from the close juxtaposition of seed and fertilizer, root development in particular being stimulated by phosphatic manures placed close to the seed: but the best relative position of seed and fertilizer is still a matter requiring much investigation. Less fertilizer is needed when combine drilling is practised than when the manure is first broadcast and worked into the soil. There is, too, a saving in time and labour, for at least one operation is saved by the use of the combine drill.

Transplanting machines for use with cabbages, leeks and similar plants have been tremendously developed, as have potato planters. Some machines will plant potatoes and simultaneously drop fertilizers into the drill; scientific evidence is now available which shows that these automatically deposited fertilizers are best placed in broad bands an inch or so away from the potato set, rather than in direct contact.

In barn machinery the most interesting recent innovation is the hammer mill for grinding corn and similar materials. These mills operate on an entirely different principle from the older grinding machinery, for the corn put into them is reduced by rapidly rotating 'hammers' which knock the material to pieces instead of rolling or squeezing it. A more finely divided product can often be obtained by the hammer principle than by the grinding process, and a completely unfounded belief has grown up amongst many farmers that by putting fodders such as hay and straw through a hammer mill their feeding value is increased: milling oat sheaves in this way saves the cost of threshing and may reduce the amount of work an animal has to perform in masticating its food, but its food value is not improved.

The introduction of selective weed-killers (see p. 188) for use against annual weeds in corn crops has been responsible for important developments in farm spraying machinery. To design a satisfactory sprayer it is necessary to know quite a lot about the formation and behaviour of droplets of various sizes. Much fundamental research upon these points has been carried out in connection with the spraying of fruit trees against insect and fungus pests, and many of the findings have been applicable to

weed spraying problems. The normal spray jet throws out a cone of droplets of a size dependant upon the jet orifice and the pressure behind the spray fluid. The engineering problem as it affects weed spraying is a twofold one; to design a sprayer which will given even distribution over as wide an area as possible, and which will hold a large volume of liquid without becoming too cumbersome. These two aspects have been satisfactorily dealt with, and sprayers having spray booms 30 feet or more in width and a tank capacity of 500 gallons have been in use by contractors for several years. They are actuated usually from the tractor power take-off shaft and deliver spray at a pressure of 50–200 lb. per square inch.

Nevertheless, the supply of water to such sprayers is a problem in itself, particularly since in the eastern counties where most of the contract spraying is done, water is often scarce and inconveniently situated. The natural question arises, is it necessary to use the traditional quantity of liquid, which is from 70 to 100 gallons per acre? The problem is not merely one of designing a machine which will give an even cover of spray from a limited amount of liquid. Two types of sprayer have recently been invented to perform this duty. In one type a tremendous volume of air is used to blow the spray fluid into small droplets, so that as little as four gallons or less can be dispersed over an acre. This type of machine is very heavy and expensive and is suitable only for contract work. The other type uses a flat fan-like spray instead of a conical one, is much cheaper and can be fixed to several makes of tractor. But unsuspected difficulties have arisen in the use of 'low volume' sprayers, leading to crop damage. When large volumes of spray are used the foliage of both crop and weeds is drenched, and there is a run-off of liquid which ensures that the concentration on the leaf does not rise beyond the safety point (for the crop). But low volume sprayers using the same weight of active weed-killing material per acre dissolved in only about one-tenth the liquid give a spray in which the droplets do not necessarily coalesce to form a film: the droplets are very concentrated and may destroy a crop which is completely insensitive to the same weight of herbicide dispersed in 100 gallons of

liquid. It is obvious that much research will have to be prosecuted on these points before low volume spraying becomes a safe practice for all crops.

One very interesting recent development in scientific farming made possible by engineering methods is that of grass drying. About 1925 Woodman at Cambridge carried out a number of analyses of young, growing grass approximately four to six inches long, and made the surprising discovery that it was very rich in protein. So rich is young grass in nutritive constituents that it can be looked upon as similar to a protein concentrate such as linseed cake. The proportion of carotene in young grass is also high, and this is a valuable point, because carotene is the precursor of vitamin A, one of the most important of the accessory food factors. It was also found that young grass, quickly dried, retains practically all its nutriment, and is very palatable. The interesting speculation then arose: Is it possible on a farm scale economically to cut, dry, and store young grass for winter use?

The advantages of being able to do this are very great, both from an individual and a national point of view. Even now most of the concentrated feeding stuffs used on the farm have to be imported from Empire and foreign sources; they do not contain any considerable amounts of vitamins, and they are expensive. If British farmers could make their own concentrates for winter use it would save them money, cut down imports, and be at the same time, a national insurance against scarcity in times of war. The health of our dairy herds in winter and the quality of their products might also be improved by the extra vitamins.

After several years of experiment a grass-drying plant was put on the market in 1936, and since then others have been designed and operated on farms in all parts of the country. The problem in all grass driers is to reduce the percentage of water from approximately 80 per cent to about 6 or 10 per cent in the shortest possible time without scorching or otherwise injuring the grass. To do this air is heated in furnaces burning coke, coal or oil, and is brought into contact with the grass in various ways. In the tray, or batch, drier the warm air at a temperature of 300 degrees

F. is driven or sucked through layers of grass contained in trays with perforated bottoms. This type of drier is cheap to instal but requires continuous attention. In another type of drier the green material is carried through the drying oven on a moving belt or conveyor, and frequently a self-feeding device is incorporated so that a load can be evenly and automatically delivered to the conveyor. A third type of drier uses air at a very much higher temperature—from 1000 to 1800 degrees F.—and chops the grass into small pieces before blowing it into a revolving drum. The grass here is dried in the space of about one minute.

Each type of drier has its own advantages and drawbacks, and it is quite certain that driers will undergo much development during the next few years. Theoretically 1 lb. of coke should give out enough heat to evaporate 11 lb. of water, but this standard is not achieved in present-day farm driers: the output, too, of farm driers needs increasing, and this can to some extent be brought about by allowing the grass to wilt for several hours before drying. But wilting brings its own problems, such as decrease in protein and vitamin content if the wilting is prolonged, and the necessity for separate cutting and loading operations, whereas with special machinery now available it is possible to cut and load (and even to chop into small pieces) in one operation.

The dried grass or dried lucerne as it leaves the drier is either baled in a baler and tied up with twine, or is put through a hammer mill and pulverized, in which case it is stored in paper bags. Baling is the usual practice where the dried grass is to be used on the same farm, since dried grass meal is powdery and rather awkward to feed without being moistened in some way.

Dried grass meal can now be compressed into small solid cubes about an inch long, which are very convenient to handle and easy to feed to stock. The cubes closely resemble those made from imported concentrates which have long been familiar to farmers.

One of the most useful engineering developments of the last thirty years is the milking-machine, which has taken much of the drudgery out of milking and has done a great deal to solve the

labour supply on dairy farms. During the last two decades of last century primitive attempts were made to remove milk from the cow's udder by means of thin metal tubes inserted in the teats, and later on pressure machines were used to simulate hand milking. These attempts all ended in failure, and the first suction machines which came in with the twentieth century were scarcely more successful. It was not until well after the first world war that efficient and reliable machines were marketed; but during the last ten years great advances have been made both in the manufacture of machines and in the technique of using them.

The essential features of a milking-machine are a vacuum pump, a pulsator, a set of teat cups and their rubber connections, and a vessel to catch the milk. The vacuum pump is worked by an electric or petrol motor, and it creates a suction which is transferred to the teat cups by a pipe line. The outer metal casing of the teat cup has a lining of rubber with a space between. By means of the pulsator this space is connected first with air at atmospheric pressure and then with air at a 'suction' pressure of about half normal atmospheric pressure. This causes the rubber linings to imitate the normal sucking of the calf, and the milk is drawn from the udder by suction. Usually there are from 45 to 65 pulsations a minute. In the usual 'bucket' type plant the suction pipe is placed in a convenient position in the cowshed and is connected to the individual units by rubber tubes, attached when needed to the numerous taps on the suction pipe. The four cups are positioned on the teats, where they are held by the suction, and the milk passes into a container holding several gallons which is emptied after each cow has been milked. It is possible now to buy portable, self-contained milking plants which do not need a central suction pipe installation.

With refinements in methods of creating a suitable vacuum and improvements in stainless steel tubing and fitments, certain pioneer farmers seized the chance of breaking away completely from the traditional methods of housing and milking cows. They did not like the traditional cow house, with the animals permanently, or almost permanently, tied up during the winter on concrete standings: they objected to the labour involved in re-

moving manure and keeping such buildings clean: they felt that the cows would be healthier if given more freedom: and they thought that milking could be done more expeditiously if the cows walked to the milking place instead of the milking apparatus being carried to each cow in turn. Thus there have been developed in recent years various types of milking parlour. A milking parlour is essentially an arrangement in which cows are milked in batches usually of from two to six at a time. In some systems the cows receive the concentrated part of their ration whilst being milked. The milk is usually drawn off by mechanically operated teat cups into a fixed container or 'releaser' which automatically weighs it, and then allows it to flow into the dairy without further attention and without passing into individual buckets. There are two main types of milking parlour, the abreast type and the tandem type. In the abreast type the cows stand side by side in separate standings, where they are washed as well as milked, and this usually gives them plenty of time to eat their concentrates: a three-unit parlour therefore has six standings, in any three of which cows are being prepared for milking whilst in the other three milking is in operation. In the tandem parlour cows stand one behind the other in separate stalls where milking only is carried out: washing has to be done before the cows enter the parlour. The milking operators usually work in a kind of well some eighteen inches lower than the floor of the standings, an arrangement which reduces stooping to a minimum.

Milking parlours have both advantages and disadvantages: they may suit one man and make no appeal to another. There is not much point in installing a milking parlour if cows are kept in the usual kind of shed or byre. If a new dairy farm is being built it may be cheaper to have a parlour and the necessary assembly and dispersal yards, together with the yards in which the cattle are housed. It is often cheaper to adapt existing buildings to the system than to erect a new cow house. It is claimed that it is cheaper to operate the parlour system, and that milk recording is simplified. On the other hand the parlour system does not permit the same close individual attention to the cows

which dairy farmers consider so important: dehorning becomes advisable, if not essential, with some breeds of dairy cattle kept in yards: and very large quantities of straw are needed. In all cases the siting of the parlour and the associated yards calls for the most careful thought if full benefits from the system are to be obtained.

One of the earliest forms of milking parlour to be developed was the milk bail, or open-air milking outfit. This is a wooden shed on wheels capable of accommodating several cows at a time. It is accompanied by another house on wheels containing an engine and a milking-machine. The complete outfit is taken by a tractor to the fields in which the cows are out at grass, and milking is performed in the open air. There are no large overhead costs in the shape of expensive cowhouses where this method is adopted, and by keeping the animals always in the open certain diseases are avoided; in addition, the pastures on light, dry land may be much improved, since the manure is returned direct to the land, but on some soils severe poaching of the surface may occur. Naturally, this system needs a not too extreme winter climate. On some farms the bail is brought close to the homestead in winter, resting on a special concrete floor.

An ingenious use of electric current is now being made by poultry keepers to encourage hens to lay more eggs in winter when prices are high. By means of a time-switch, poultry laying-houses are illuminated after dark for an hour or two to encourage more scratching and to discourage the normal roosting which takes place when the sun has set. It is found that this extra exercise results in more eggs per bird, whose value is much greater than the extra cost of the illumination.

An invention which has been of the very greatest value is the electric fence. Hitherto it has been necessary to rely upon living hedges or upon fences of wood or wire to keep stock within bounds. Live hedges are expensive to maintain, and they cannot, of course, be moved. Fences made of wood or iron posts supporting rails or wire or hurdles, are expensive and take much time and labour to move and erect. The electric fence, however, is very portable and can be erected quickly. It consists usually

of a six volt car battery passing a current through a transformer which raises the voltage in the fencing wire high enough to give any animal coming in contact with it a distinct shock. The amperage, or volume of current, is, however, so small that no harm can possibly result, and since the current is caused to 'make-and-break' by a suitable mechanism the battery retains its life for a long period. The current is transmitted by a plain or barbed wire held on insulated posts, and the unit is capable of electrifying several miles of wire. Once animals have become schooled to the shock they are reluctant to approach the wire; in consequence, only light, very portable posts need be used. These electric fences have proved very useful for the controlled grazing of leys, and most classes of stock, including pigs, can be kept within bounds. Care is necessary to prevent the fence from being rendered 'dead' through short circuits brought about by vegetation and other materials coming in contact with the wire.

One interesting problem that the engineer is trying to solve is that of 'rotary' cultivation. Traditional methods of preparing a seed bed involve three or more separate operations in which the soil is moved from side to side. Ploughing, harrowing, and rolling are necessary to break down the soil into a fine state. Is it justifiable to use a tractor on these implements, designed for slow-moving oxen or horses? Why not make a tilth in one operation by an implement having rotating teeth or blades. There are such implements in use doing satisfactory work on market garden soils, but their use on the general farm has not been extensive. An early attempt to solve the problem took the form of a very large and heavy machine called a 'Gyrotiller'; in this machine vertical rotating tines of great strength are used to stir the soil to a depth of from six to eighteen inches or more without bringing the subsoil to the surface. In more recent machines horizontal blades are caused to rotate at varying speeds relative to the forward speed of the tractor to which the implement is attached. Naturally the wear on the blades can be severe in stony soil, but it is claimed that the blades can be renewed at a less cost than the shares on a plough. Rotary cultivations of this

sort are now being used to deal with the straw left by combine harvesters.

Power is being applied to almost every farm operation, including hoisting, stacking, milk loading, moving grain, etc. There are two main objects in this, the lowering of costs and the elimination of drudgery.

COLLATERAL READING

The standard work in this country is *Farm Machinery*, by C. Culpin (Crosby Lockwood, 1947) which should be read in conjunction with J. C. Hawkes's *The Mechanical Equipment of Farms* (Spon, 1949) and *Field Machinery*, by Cornelius Davies (Nelson, 1949). Other useful books are *Good Farming by Machine*, by H. J. Hine (English Universities Press, 1948) and *Farming Equipment*, by A. J. Brookes (Pitman, 1946). *Combine Harvesting and Grain Drying* (National Federation of Gas and Coke Associations, 1945) deals with a problem which, however, has developed considerably since the brochure was published. T. A. Oxley's *The Scientific Principles of Grain Storage* (Northern Publishing Co., 1948) is one of the most recent expositions of an increasingly important subject. The reader should not omit to obtain the quarterly publication of the National Institute of Agricultural Engineering, called *Engineering Record*. *The Implement and Machinery Review*, *British Farm Mechanization*, and *Power Farmer* are published monthly.

Chapter Eleven

EDUCATION, RESEARCH AND ADVISORY WORK

Present position of agricultural education—Farm Institutes—Agricultural Colleges—University Departments—research—the Research Institutes—Commonwealth Agricultural Bureaux—the National Agricultural Advisory Service—the Provincial Centres.

Agricultural education in England and Wales has undergone many changes during the past fifty years, and just now is passing through another transition period brought about mainly as the result of war conditions. In general it may be said that there are three phases, or stages, in agricultural education to-day represented by the Farm Institute, the Agricultural College and the University.

The Farm Institute is under the control of the Local Education Authority, which for the most part means the County Council, though grants are made through the Ministry of Agriculture. At Farm Institutes the training given to the students usually covers at most a period of twelve months, and frequently the courses are much shorter, covering three months or less. At some institutes courses longer than one year may be provided. No prescribed standards of education are demanded of prospective entrants, but a knowledge of the practical side of farming is usually required. The course of study is naturally more elementary than in the other educational institutions.

Farm Institutes have been opened in the following counties, and others are projected:

England

Berkshire—Institute of Agriculture, Hurley.

Cheshire—School of Agriculture, Reaseheath, Nantwich.

Cumberland—Cumberland and Westmorland Farm School, Newton Rigg, Penrith.

Derbyshire—County Farm Institute, Broomfield Hall, Morley, Nr. Derby.

Devonshire—Farm Institute, Bicton, East Budleigh.

Dorset—Farm Institute, Kingston Maurward, Nr. Dorchester.

Durham—County School of Agriculture, Houghall, Durham.

Essex—Institute of Agriculture, Writtle, Chelmsford.

Gloucestershire—Farm Institute, Hartpury, Gloucester.

Hampshire—County Farm Institute, Sparsholt, Winchester.

Hertfordshire—Institute of Agriculture, Oaklands, St. Albans.

Kent—Farm Institute—Sittingbourne; Horticultural Institute, Swanley.

Lancashire—County Institute of Agriculture, Hutton, Preston, and Winmarleigh Hall.

Lincolnshire (Kesteven)—Farm Institute, Caythorpe Court, Nr. Grantham.

Lincolnshire (Lindsey)—Farm Institute, Riseholme, Nr. Lincoln.

Northamptonshire—Institute of Agriculture, Moulton, Northampton.

Nottinghamshire—Farm Institute, Brackenhurst, Southwell.

Shropshire—Farm Institute, Walford, Nr. Baschurch.

Somerset—Farm Institute, Cannington, Bridgwater.

Staffordshire—Farm Institute, Penkridge, Stafford.

Surrey—Farm Institute, Merrist Wood, Worplesdon, Guildford.

Sussex—East Sussex School of Agriculture, Plumpton.
Warwickshire—Institute of Agriculture, Moreton Morrell, Nr. Warwick.
Yorkshire—Farm Institute, Askham Bryan, York.

Wales

Carnarvonshire—Madryn Castle Farm Institute, Bodvean, Pwllheli.
Carmarthenshire—Pibwrlwyd Farm Institute, Carmarthen.
Denbighshire—Llysfasi Farm Institute, Ruthin.
Monmouthshire—Institute of Agriculture, Usk.

The following institutions not under the control of County Councils also provide instruction:

Avoncroft College, Stoke Prior, Bromsgrove, Worcestershire.
The Shuttleworth College, Old Warden Park, Biggleswade, Bedfordshire.
Henry Ford Institute of Agricultural Engineering, Borehame, Essex.

There are four independent Agricultural Colleges in England which accept students for periods of training lasting as a rule either one or two years: special courses of varying duration are also available. These colleges have their own laboratories and farms, and grant diplomas to successful students; students are also trained for the national diplomas such as the National Diploma in Agriculture (N.D.A.), National Diploma in Poultry Husbandry (N.D.P.), and National Diploma in Horticulture (N.D.H.).

The four agricultural colleges are:

Harper Adams Agricultural College, Newport, Shropshire.
Royal Agricultural College, Cirencester, Gloucestershire (men only).
Seale-Hayne Agricultural College, Newton Abbot, Devonshire.
Studley College, Warwickshire (women only).

Certain universities have Faculties of Agriculture for the training of students who wish to take either a pass degree or an honours degree in agriculture or in one of its branches. The period of study covers usually either three or four years. (Some universities still offer diploma courses as well.) In England and Wales these universities are as follows:

England

University of Cambridge (School of Agriculture).
University of Durham (King's College, Newcastle-on-Tyne).
University of Leeds.
University of London (Wye College, Kent).
University of Nottingham (School of Agriculture, Sutton Bonington, Loughborough).
University of Oxford (Department of Agriculture).
University of Reading.

Wales

University of Wales
(University College of Wales, Aberystwyth.)
(University College of North Wales, Bangor.)

Research into agricultural problems is carried out in several different ways. Individual teachers at colleges and universities may interest themselves in particular problems and publish their results independently, while in other, mainly teaching, institutions there may be some form of organized research. A number of commercial firms maintain their own research organizations. There are also special Research Institutes, maintained wholly or in part from public funds, whose major work is to investigate special aspects of agricultural problems. These Research Institutes are listed below in alphabetical order of their subjects of research:

Animal Nutrition: Animal Nutrition Research Institute, School of Agriculture, Cambridge.
Animal Pathology (Diseases): Institute of Animal Pathology,

Cambridge; Ministry of Agriculture Veterinary Laboratory, New Haw, Weybridge, Surrey; Royal Veterinary College, Camden Town, London, N.W.1

Botany: Royal Botanic Gardens, Kew.

Crop Testing: Development of new varieties of crops: Seed Testing: Potato Testing: National Institute of Agricultural Botany, Huntingdon Road, Cambridge.

Dairying: National Institute for Research in Dairying, Shinfield, Nr. Reading.

Economics: Agricultural Economics Research Institute, Parks Road, Oxford.

Engineering: National Institute of Agricultural Engineering, Wrest Park, Silsoe, Bedfordshire.

Fruit Culture: Agricultural and Horticultural Research Station, Long Ashton, Bristol; Fruit and Vegetables Preserving Station (Bristol University), Campden, Glos.; East Malling Research Station, East Malling, Kent.

Parasitology: Institute of Agricultural Parasitology (Helminthology); (London School of Hygiene and Tropical Medicine), Winches Farm, 395 Hatfield Road, St. Albans.

Grassland: Grassland Research Institute, Drayton, Stratford-on-Avon (and Hurley, Berks.).

Plant Breeding (Horticultural Crops) John Innes Horticultural Institution, Bayfordbury, Hertford.

Plant Breeding (Cereals): Plant Breeding Research Institute, School of Agriculture, Cambridge.

Plant Breeding (Grasses and Forage Crops): Welsh Plant Breeding Station, Penglais, Aberystwyth.

Plant Pathology: Ministry of Agriculture Pathological Laboratory, Harpenden, Herts; Rothamsted Experimental Station, Harpenden, Herts.

Plant Physiology: Institute for Research in Plant Physiology, Imperial College, South Kensington, S.W.7.

Plant Virus Research Station, School of Agriculture, Cambridge.

Small Animal Breeding: Small Animal Breeding Research Institute, School of Agriculture, Cambridge.

Soils and Plant Nutrition: Rothamsted Experimental Station, Harpenden, Herts.

Vegetables Vegetable Research Station, Wellesbourne, Warwickshire, and Paglesham, Essex.

Commonwealth Agricultural Bureaux were first formed in 1929 (then called the Imperial Agricultural Bureaux) to act as an effective clearing house for the interchange of information of value to research workers in agricultural science throughout the various parts of the Commonwealth and Empire. The headquarters are at 2 Queen Anne's Gate Buildings, London, S.W. 1. The organization comprises the following Bureaux and Institutes: the Abstract, Journal, or other publications for which each centre is responsible is mentioned within brackets.

AGRICULTURAL PARASITOLOGY (HELMINTHOLOGY)
Winches Farm Drive,
395 Hatfield Road,
St. Albans, Herts.
(*Helminthological Abstracts*)

ANIMAL BREEDING AND GENETICS
Institute of Animal Genetics,
University of Edinburgh,
King's Buildings,
West Mains Road,
Edinburgh, 9.
(*Animal Breeding Abstracts*)

ANIMAL HEALTH
Veterinary Laboratory,
New Haw,
Weybridge,
Surrey.
(*The Veterinary Bulletin*)

ANIMAL NUTRITION
Rowett Research Institute,
Bucksburn,
Aberdeen.
(*Nutrition Abstracts and Reviews*)

BIOLOGICAL CONTROL
228 Dundas Street,
Belleville,
Ontario, Canada.

DAIRY SCIENCE
Shinfield,
Near Reading.
(*Dairy Science Abstracts*)

COMMONWEALTH FORESTRY BUREAU
New Bodleian Building,
Parks Road,
Oxford.
(*Forestry Abstracts; Forestry Products and Utilization*)

HORTICULTURE AND PLANTATION CROPS
East Malling Research Station,
Near Maidstone,
Kent.
(*Horticultural Abstracts*)

PASTURES AND FIELD CROPS
Penglais,
Aberystwyth.
(*Herbage Abstracts; Field Crop Abstracts*)

PLANT BREEDING AND GENETICS
School of Agriculture,
Cambridge.
(*Plant Breeding Abstracts*)

SOIL SCIENCE
Rothamsted Experimental Station,
Harpenden,
Herts.
(*Soils and Fertilizers*)

COMMONWEALTH INSTITUTE OF ENTOMOLOGY
41 Queen's Gate,
London, S.W. 7.
(*Review of Applied Entomology*)

COMMONWEALTH MYCOLOGICAL INSTITUTE
Commonwealth Mycological Institute,
Ferry Lane,
Kew,
Surrey.
(*Review of Applied Mycology*)

COMMONWEALTH POTATO COLLECTION
Huntingdon Road,
Cambridge.

The making of a discovery of importance and value to agriculture is one thing; it is quite another matter to interpret this discovery in the light of farm practice and to get the story across to individual farmers. Since 1946 there has been in existence an organization called the National Agricultural Advisory Service whose duty it is to advise farmers upon their problems, and also to indicate to research stations and similar bodies what problems need tackling on the farmer's behalf. For many years prior to the 1939 war farmers were able to obtain advice from officers

appointed by the County Councils, but during the war this advisory work was taken over by the War Agricultural Executive Committees and the advisory staffs were expanded. In 1946 a National Agricultural Advisory Service was set up for England and Wales as a section of the Ministry of Agriculture and Fisheries, and its responsibilities as described by the Director General of the Service are as follows:

1. To disseminate among food producers, scientific and technical knowledge, including particularly such new knowledge as can usefully be applied in the field.
2. To provide advice to individual farmers on technical matters related to food production, and to instruct workers in new methods and the operation of new machines.
3. To carry out such experiments and investigations as may be required to determine the local applicability of new discoveries and inventions, and to pass on, to the Research Institutes, problems that seem to call for fundamental investigations.
4. To provide technical guidance to County Agricultural Committees, who act as the agents of the Minister in promoting food production.
5. To operate, on behalf of the Ministry, various particular schemes directed to the improvement of food production, the most important being:

    (a) the inspection and licensing of bulls, boars and rams with the object of preventing the use for breeding of inferior animals;
    (b) the inspection and accreditation of breeding flocks of poultry, and
    (c) the inspection and certification of growing crops of cereals, potatoes, herbage plants and vegetables from which seed is to be harvested, and of fruit stocks which are to be sold for planting.

The N.A.A.S. is really based upon technically trained men called District Officers, who are placed in charge of a district

within a county, covering about 1,000 farm holdings. The District Officer is under the direction of a County Agricultural Officer, who also has on his staff a number of county specialists in horticulture, machinery, poultry and dairying. It is the duty of these officers to work with County and District Committees in advising farmers on day-to-day farming problems.

For the purpose of administering the N.A.A.S., England and Wales[1] have been divided up into eight Provinces, each in charge of a Provincial Director, with a staff of provincial specialist officers whose task it is to help in solving problems which the District Officer or County Officer is unable to tackle; to carry out analyses of soils and feeding stuffs; to co-ordinate experiments, and to keep the general officers informed of new developments. There are three branches of the service, comprising numerous departments as follows :

(1)	Science	Soil Science, Animal Nutrition, Entomology, Plant Pathology, Bacteriology.
(2)	Husbandry	Crops, Grassland, Machinery, Livestock, Poultry, Milk Production.
(3)	Horticulture	Fruit, Vegetable Crops, Glasshouse Crops and Flowers.

Each of the main branches is looked after by a senior officer in London, who with the Director and Director General and a number of administrative officers form the Headquarters Staff.

Also forming part of the service is a number of experimental farms and horticultural stations scattered about the Provinces on sites chosen because they represent particular soil types and climatic conditions. It is intended that crops, fertilizers, livestock, farming systems and so forth shall be tested on these farms to obtain reliable information for passing on to the general farmer. These farms will work in close harmony with existing experimental stations, and they should provide the provincial specialists with opportunities for their own investigations. Not

[1] Scotland has its own separate organization for agricultural advisory work.

all of the fourteen experimental farms have yet been acquired and it will, of course, be some years before their programmes can be brought into full operation.

The eight Provinces comprising the National Agricultural Advisory Service are as follows:

Province	*Provincial Centre*
NORTHERN	
Northumberland, Cumberland, Durham, Westmorland	Newcastle
Address: Elswick Hall, Elswick Park, Newcastle 4.	
YORKSHIRE AND LANCASHIRE	Leeds
Address: Quarry Dene, Weetwood Lane, Leeds 6.	
WEST MIDLAND	
Cheshire, Staffordshire, Shropshire, Herefordshire, Worcestershire, Warwickshire	Wolverhampton
Address: 'Woodthorne', Wergs Road, Tettenhall, ('Woodthorne', Wolverhampton), Staffs.	
EAST MIDLAND	
Derbyshire, Nottinghamshire, Lincolnshire (Kesteven and Lindsey), Leicestershire, Rutland, Northamptonshire	Shardlow (Near Derby)
Address: Shardlow Hall, Shardlow, Near Derby.	
EASTERN	
Lincolnshire (Holland), Norfolk, Cambridge, Isle of Ely, Huntingdonshire, Soke of Peterborough, Bedfordshire, Suffolk (East and West), Hertfordshire, Essex	Cambridge
Address: Anstey Hall, Trumpington, Cambridge.	

SOUTH-EASTERN

Oxfordshire, Buckinghamshire, Berkshire, Middlesex, Surrey, Hampshire and Isle of Wight, Sussex (East and West), Kent	Reading

Address: Chiltern Court, St. Peter's Avenue, Caversham, Reading.

SOUTH-WESTERN

Gloucestershire, Wiltshire, Somerset, Dorset, Devon, Cornwall, Isles of Scilly	Bristol

Address: Crete Hill, Westbury-on-Trym, Bristol.

WALES

Welsh Counties and Monmouthshire	Aberystwyth

Address: Trawscoed, Aberystwyth.

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